PB86-104577

Commencement Bay Nearshore/Tideflats Remedial Investigation. Volume 2

Tetra Tech, Inc., Bellevue, WA

Prepared for

Washington State Dept. of Ecology, Olympia

Aug 85

U.S. Department of Commerce
National Technical Information Service
NTIS

PB86-104577

TC-3752
FINAL REPORT
EPA-910/9-85-134b

COMMENCEMENT BAY NEARSHORE / TIDEFLATS REMEDIAL INVESTIGATION

VOLUME 2

AUGUST, 1985

PREPARED FOR:
WASHINGTON STATE DEPARTMENT OF ECOLOGY
AND U.S. ENVIRONMENTAL PROTECTION AGENCY

Mr. James D. Krull, Project Manager
Washington State Department of Ecology
Olympia, Washington

TETRA TECH

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TC-3752
Final Report

COMMENCEMENT BAY NEARSHORE/ TIDEFLATS REMEDIAL INVESTIGATION

Volume 2

by

Tetra Tech, Inc.

for

Washington State Department of Ecology
U.S. Environmental Protection Agency

Mr. James D. Krull, Project Manager
Washington State Department of Ecology
Olympia, Washington

August, 1985

Tetra Tech, Inc.
11820 Northup Way, Suite 100
Bellevue, Washington 98005

50272-101

REPORT DOCUMENTATION PAGE	**1. REPORT NO.** EPA 910/9-85-134b Vol 2	**2.**	**3. Recipient's Accession No.** PB86 104577

4. Title and Subtitle

Commencement Bay Nearshore/Tideflats Remedial Investigation
Volume 2

5. Report Date

August 1985

6.

7. Author(s)

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

Tetra Tech, Inc.
11820 Northup Way, Suite 100
Bellevue, WA 98005

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.

(C)

(G)

12. Sponsoring Organization Name and Address

U.S. Environmental Protection Agency Region 10
1200 6th Avenue
Seattle, WA 98101

13. Type of Report & Period Covered

14.

15. Supplementary Notes

Appendices, EPA 910/9-85-134c; Vol. 3, Appendices I-V and Vol. 4, Appendices VI-XX are included on microfiche at the end of this volume

16. Abstract (Limit: 200 words)

This report represents work completed under the U.S. EPA/WDOE Cooperative Agreement for Tasks 3, 4, and 5 of the Commencement Bay Superfund Investigation. The investigation includes various integrated program components; assessments of chemical contamination, biological effects, toxicity, public health concerns, source identification, and identification of potential remedial actions and technologies.

17. Document Analysis a. Descriptors

REmedial Investigations
Sediments
Contamination

b. Identifiers/Open-Ended Terms

Commencement Bay
Puget Sound

c. COSATI Field/Group

18. Availability Statement	**19. Security Class (This Report)**	**21. No. of Pages**
	20. Security Class (This Page)	**22. Price**

(See ANSI–Z39.18) See Instructions on Reverse

OPTIONAL FORM 272 (4–77)
(Formerly NTIS–35)
Department of Commerce

CONTENTS VOLUME 2

Page

LIST OF FIGURES iv

LIST OF TABLES xi

CONTENTS VOLUME I xiv

7.0 SOURCE EVALUATION 7.1

7.1 INTRODUCTION 7.1

7.2 HYLEBOS WATERWAY 7.5

- 7.2.1 Introduction 7.5
- 7.2.2 Contaminants of Concern 7.8
- 7.2.3 Polychlorinated Biphenyls 7.13
- 7.2.4 Aromatic Hydrocarbons 7.22
- 7.2.5 Dibenzofuran 7.38
- 7.2.6 Benzyl Alcohol 7.40
- 7.2.7 Chlorinated Hydrocarbons 7.43
- 7.2.8 Pentachlorocyclopentane Isomer 7.73
- 7.2.9 Arsenic 7.76
- 7.2.10 Copper, Lead, and Zinc 7.84
- 7.2.11 Mercury 7.106
- 7.2.12 Hylebos Waterway: Summary and Recommendations 7.110

7.3 SITCUM WATERWAY 7.115

- 7.3.1 Introduction 7.115
- 7.3.2 Aromatic Hydrocarbons and Dibenzofuran 7.119
- 7.3.3 Metals 7.124

7.4 ST. PAUL WATERWAY 7.138

- 7.4.1 Introduction 7.138
- 7.4.2 Spatial Distribution 7.142
- 7.4.3 Loading Estimates 7.150
- 7.4.4 Source Identification 7.153
- 7.4.5 Summary and Recommendations 7.159

7.5 MIDDLE WATERWAY 7.160

- 7.5.1 Introduction 7.160
- 7.5.2 Pentachlorophenol and Dichlorobenzenes 7.164
- 7.5.3 Aromatic Hydrocarbons and Dibenzofuran 7.169
- 7.5.4 Mercury and Copper 7.173
- 7.5.5 Middle Waterway: Summary and Recommendations 7.179

7.6 CITY WATERWAY 7.181

7.6.1 Introduction 7.181
7.6.2 Contaminants of Concern 7.183
7.6.3 Organic Enrichment 7.190
7.6.4 Aromatic Hydrocarbons and Dibenzofuran 7.197
7.6.5 Dichlorobenzenes 7.209
7.6.6 4-Methylphenol 7.217
7.6.7 Polychlorinated Biphenyls 7.223
7.6.8 Copper and Zinc 7.227
7.6.9 Lead 7.236
7.6.10 Summary and Recommendations 7.241

7.7 RUSTON-PT. DEFIANCE SHORELINE 7.244

7.7.1 Introduction 7.244
7.7.2 Spatial Distribution 7.249
7.7.3 Loading Estimates 7.262
7.7.4 Source Identification 7.266
7.7.5 Summary and Recommendations 7.277

8.0 RECOMMENDATIONS OF AREAS AND SOURCES FOR POTENTIAL REMEDIAL ACTIONS 8.1

8.1 INTRODUCTION 8.1

8.2 RECOMMENDATIONS FOR REMEDIAL ACTION 8.4

8.2.1 Hylebos Waterway 8.4
8.2.2 Sitcum Waterway 8.5
8.2.3 St. Paul Waterway 8.5
8.2.4 Middle Waterway 8.6
8.2.5 City Waterway 8.6
8.2.6 Ruston - Pt. Defiance Shoreline 8.7

8.3 GENERAL RECOMMENDATIONS 8.7

9.0 OVERVIEW OF CONTAMINATION AND BIOLOGICAL EFFECTS IN COMMENCEMENT BAY 9.1

10.0 STUDY DESIGN EVALUATION AND RECOMMENDATIONS FOR FUTURE STUDIES 10.1

10.1 SEDIMENT CHEMISTRY 10.1
10.2 BIOLOGICAL EFFECTS 10.2
10.3 DECISION-MAKING APPROACH 10.4
10.4 SOURCE IDENTIFICATION 10.5

11.0 REFERENCES 11.1

FIGURES

Number		Page
7.1.1	Problem areas and their respective contaminants of concern for which source identification has been pursued	7.3
7.2.1	Major industries surrounding the Hylebos Waterway from Port of Tacoma - summary of port services, facilities, and industries	7.6
7.2.2	Discharges to the Hylebos Waterway noted in the text and their locations along the waterfront	7.7
7.2.3	Dredging activity in the Hylebos Waterway	7.9
7.2.4	Surficial sediment stations and sediment core locations from all Hylebos Waterway studies in the project database	7.10
7.2.5	Areas of Hylebos Waterway with the greatest concentrations of each contaminant of concern in the surficial sediments	7.12
7.2.6	Concentrations of total PCBs in the surficial sediments of the Hylebos Waterway with distance from the mouth of the waterway	7.14
7.2.7	Concentrations of total PCBs in the surficial sediments of the Hylebos Waterway Segment 5	7.15
7.2.8	Concentrations of total PCBs with depth in the sediment column	7.17
7.2.9	Concentrations of total PCBs in the surficial sediments of Hylebos Waterway Segments 2 and 3	7.18
7.2.10	Concentrations of total PCBs with depth in the sediment column	7.19
7.2.11	Concentrations of total low molecular weight polycyclic aromatic hydrocarbons in the surficial sediments of the Hylebos Waterway with distance from the mouth of the waterway	7.23
7.2.12	Surficial sediment concentrations of LPAH in Hylebos Waterway	7.24
7.2.13	Concentrations of total high molecular weight polycyclic aromatic hydrocarbons in the surficial sediments of the Hylebos Waterway with distance from the mouth of the waterway	7.26

7.2.14 Surficial sediment concentrations of HPAH in Hylebos Waterway 7.27

7.2.15 Ratio of the concentrations of total high molecular weight PAH to total low molecular weight PAH at all Tetra Tech survey stations in the Hylebos Waterway 7.28

7.2.16 Concentrations of PAH with depth in the sediment column 7.29

7.2.17 Concentrations of dibenzofuran in the surficial sediments of the Hylebos Waterway with distance from the mouth of the waterway 7.39

7.2.18 Concentrations of benzyl alcohol in the surficial sediments of the Hylebos Waterway with distance from the mouth of the waterway 7.41

7.2.19 Concentrations of hexachlorobenzene in the surficial sediments of the Hylebos Waterway with distance from the mouth of the waterway 7.44

7.2.20 Concentrations of 1,4-dichlorobenzene in the surficial sediments of the Hylebos Waterway with distance from the mouth of the waterway 7.45

7.2.21 Concentrations of hexachlorobenzene in the surficial sediments of Hylebos Segment 5 7.46

7.2.22 Concentrations of total chlorinated butadienes in the surficial sediments of the Hylebos Waterway with distance from the mouth of the waterway 7.47

7.2.23 Concentrations of hexachlorobutadiene in the surficial sediments of the Hylebos Waterway with distance from the mouth of the waterway 7.48

7.2.24 Concentrations of tetrachloroethene in the surficial sediments of the Hylebos Waterway with distance from the mouth of the waterway 7.49

7.2.25 Concentrations of chlorinated butadienes with depth in the sediment column 7.51

7.2.26 Concentrations of chlorinated benzenes with depth in the sediment column 7.52

7.2.27 Flow schematic of chlorine production and chlorinated organic waste handling at Occidental Chemical Corporation 7.60

7.2.28 Location of groundwater monitoring wells at Occidental Chemical Corporation 7.64

7.2.29 Concentration of chlorinated organic compounds in groundwater beneath Occidental Chemical Corporation 7.65

7.2.30 Concentrations of tetrachloroethene in groundwater monitoring wells on the property of Pennwalt Corporation 7.66

7.2.31 Relationship between chloroform and tetrachloroethene concentrations in groundwater beneath the Pennwalt property 7.69

7.2.32 Concentrations of pentachlorocyclopentane in the surficial sediments of the Hylebos Waterway with distance from the mouth of the waterway 7.74

7.2.33 Concentrations of arsenic in the surficial sediments of the Hylebos Waterway with distance from the mouth of the waterway 7.77

7.2.34 Concentrations of copper in the surficial sediments of the Hylebos Waterway with distance from the mouth of the waterway 7.85

7.2.35 Concentrations of lead in the surficial sediments of the Hylebos Waterway with distance from the mouth of the waterway 7.86

7.2.36 Concentrations of zinc in the surficial sediments of the Hylebos Waterway with distance from the mouth of the waterway 7.87

7.2.37 Concentrations of nickel in the surficial sediments of the Hylebos Waterway with distance from the mouth of the waterway 7.89

7.2.38 Concentrations of metals with depth in the sediment column 7.90

7.2.39 Concentrations of mercury in the surficial sediments of the Hylebos Waterway with distance from the mouth of the waterway 7.107

7.2.40 Sources of contaminants to the Hylebos Waterway 7.111

7.3.1 Industries within the Sitcum Waterway drainage area 7.117

7.3.2 Surficial sediment stations and the sediment core location from all studies in Sitcum Waterway 7.118

7.3.3 Concentrations of low molecular weight PAH in surficial sediments of Sitcum Waterway 7.120

7.3.4 Concentrations of high molecular weight PAH in surficial sediments of Sitcum Waterway 7.121

7.3.5 Concentrations of dibenzofuran in surficial sediments of Sitcum Waterway 7.122

7.3.6 Concentrations of copper in surficial sediments of Sitcum Waterway 7.125

7.3.7 Concentrations of zinc in surficial sediments of Sitcum Waterway 7.126

7.3.8 Concentrations of lead in surficial sediments of Sitcum Waterway 7.127

7.3.9 Concentrations of arsenic in surficial sediments of Sitcum Waterway 7.129

7.4.1 Major industries and discharges to the St. Paul Waterway 7.139

7.4.2 Surficial sediment stations and sediment core locations from all studies in the St. Paul Waterway 7.141

7.4.3 Concentrations of total organic carbon (%) in the surficial sediments of the St. Paul Waterway 7.143

7.4.4 Concentrations of 4-methylphenol in the surficial sediments of the St. Paul Waterway 7.144

7.4.5 Concentrations of 2-methoxyphenol in the surficial sediments of the St. Paul Waterway 7.145

7.4.6 Concentrations of 1-methyl-2-(1methylethyl)benzene in the surficial sediments of the St. Paul Waterway 7.146

7.4.7 Concentrations of naphthalene in the surficial sediments of the St. Paul Waterway 7.147

7.4.8 Concentrations of 2-methylnaphthalene in the surficial sediments of the St. Paul Waterway 7.148

7.4.9 Concentrations of copper in the surficial sediments of the St. Paul Waterway 7.149

7.5.1 Major industries and discharges to the Middle Waterway 7.161

7.5.2 Surficial sediment stations and sediment core locations from all studies in Middle Waterway 7.163

7.5.3 Concentrations of pentachlorophenol in the surficial sediments of the Middle Waterway 7.165

7.5.4 Concentrations of 1,4-dichlorobenzene in the surficial sediments of Middle Waterway 7.166

7.5.5 Concentrations of low molecular weight PAH in the surficial sediments of Middle Waterway 7.170

7.5.6 Concentrations of high molecular weight PAH in the surficial sediments of Middle Waterway 7.171

7.5.7 Concentrations of dibenzofuran in the surficial sediments of Middle Waterway 7.172

7.5.8 Concentrations of copper in the surficial sediments of Middle Waterway 7.174

7.5.9 Concentrations of mercury in the surficial sediments of Middle Waterway 7.175

7.6.1 Industries surrounding City Waterway 7.182

7.6.2 Stormdrain locations and NPDES permitted discharge locations in City Waterway 7.185

7.6.3 Surficial sediment stations and sediment core locations from all studies in City Waterway 7.186

7.6.4 Areas of City Waterway with the greatest concentrations of each contaminant of concern in the surficial sediments 7.189

7.6.5 Surficial sediment concentrations of total organic carbon in City Waterway 7.191

7.6.6 Percentage of total organic carbon with depth in sediments of City Waterway 7.192

7.6.7 Surficial sediment concentrations of LPAH in City Waterway 7.198

7.6.8 Surficial sediment concentrations of HPAH in City Waterway 7.199

7.6.9 Concentration of total LPAH on a dry weight basis with depth in sediments of City Waterway 7.201

7.6.10 Concentration of total HPAH on a dry weight basis with depth in sediments of City Waterway 7.202

7.6.11 Surficial sediment concentrations of 1,4-dichlorobenzene in City Waterway 7.210

7.6.12 Surficial sediment concentrations of 1,2-dichlorobenzene in City Waterway 7.211

7.6.13 Concentrations of 1,2-dichlorobenzene and 1,4-dichlorobenzene with depth in the sediment column 7.213

7.6.14 Surficial sediment concentrations of 4-methylphenol in City Waterway 7.218

7.6.15 Concentration of 4-methylphenol with depth in the sediment column at stations in City Waterway 7.219

7.6.16 Surficial sediment concentrations of PCBs in City Waterway 7.224

7.6.17 Concentration of PCBs with depth in the sediment at Station CI-60, G05 near the head of City Waterway 7.225

7.7.18 Surficial sediment concentrations of (A) copper, and (B) zinc in City Waterway 7.228

7.6.19 Concentration of (A) copper, and (B) zinc with depth of sediment at Station CI-60, G05 near the head of City Waterway 7.229

7.6.20 Approximate drainage area served by the Nalley Valley and south Tacoma drains 7.233

7.6.21 Surficial sediment concentrations of lead in City Waterway 7.237

7.6.22 Concentration of lead with depth in the sediment at Station CI-60, G05 near the head of City Waterway 7.238

7.6.23 Locations of known and potential sources of contaminants to City Waterway 7.242

7.7.1 Major industries and discharges to the Ruston Shoreline 7.245

7.7.2 Surficial sediment stations and sediment core locations from all studies on the Ruston Shoreline 7.248

7.7.3 Concentrations of arsenic in the surficial sediments of the Ruston Shoreline 7.250

7.7.4 Concentrations of cadmium in the surficial sediments of the Ruston Shoreline 7.251

7.7.5 Concentrations of copper in the surficial sediments of the Ruston Shoreline 7.252

7.7.6 Concentrations of lead in the surficial sediments of the Ruston Shoreline 7.253

7.7.7 Concentrations of mercury in the surficial sediments of the Ruston Shoreline 7.254

7.7.8 Concentrations of zinc in the surficial sediments of the Ruston Shoreline 7.255

7.7.9 Concentrations of low molecular weight PAH in the surficial sediments of the Ruston Shoreline 7.256

7.7.10 Concentrations of high molecular weight PAH in the surficial sediments of the Ruston Shoreline 7.257

7.7.11 Concentrations of dibenzofuran in the surficial sediments of the Ruston Shoreline 7.258

7.7.12 Concentrations of 2-methyl phenol in the surficial sediments of the Ruston Shoreline 7.259

7.7.13 Concentrations of 1,4-dichlorobenzene in the surficial sediments of the Ruston Shoreline 7.260

7.7.14 Concentrations of PCBs in the surficial sediments of Ruston Shoreline 7.261

LIST OF TABLES

Number		Page
7.2.1	Discharges to the Hylebos Waterway in which PCBs have been undetected	7.21
7.2.2	Discharges to the Hylebos Waterway in which PAH have been undetected	7.31
7.2.3	Potential industrial sources of polycylic aromatic hydrocarbons in Hylebos Segments 4 and 5	7.33
7.2.4	Chlorinated ethenes: summary of loadings from discharges to Hylebos Waterway	7.54
7.2.5	Chlorinated benzenes and butadienes: summary of loadings from discharges to Hylebos Waterway	7.56
7.2.6	AWARE (1981) groundwater samples containing chloroform and/or tetrachloroethene concentrations above detection limits	7.68
7.2.7	Arsenic: summary of loadings from discharges to Hylebos Waterway	7.78
7.2.8	Copper: summary of loadings from discharges to Hylebos Waterway	7.92
7.2.9	Lead: summary of loadings from discharges to Hylebos Waterway	7.95
7.2.10	Zinc: summary of loadings from discharges to Hylebos Waterway	7.98
7.2.11	Mercury: summary of loadings from discharges to Hylebos Waterway	7.108
7.3.1	Dredging history of Sitcum Waterway	7.116
7.3.2	Concentrations of arsenic and metals with depth in the sediment	7.130
7.3.3	Arsenic: summary of loadings from discharges to the Sitcum Waterway	7.131
7.3.4	Copper: summary of loadings from discharges to the Sitcum Waterway	7.132

7.3.5 Lead: summary of loadings from discharges to the Sitcum Waterway 7.133

7.3.6 Zinc: summary of loadings from discharges to the Sitcum Waterway 7.134

7.4.1 Concentration of the contaminants of concern with depth in the sediment 7.151

7.4.2 BOD, COD, and total suspended solids: summary of loadings from discharges to the St. Paul Waterway and from the Puyallup River 7.152

7.4.3 Naphthalene and copper: summary of loadings from discharges to the St. Paul Waterway and from the Puyallup River 7.154

7.5.1 Comparison of arsenic and metal ratios in Middle Waterway sediments 7.178

7.6.1 Summary of dredging projects, City Waterway 7.184

7.6.2 COD: summary of loadings from discharges to City Waterway 7.194

7.6.3 Ratio of high molecular weight PAH to low molecular weight PAH with depth in sediments of City Waterway 7.204

7.6.4 Low molecular weight PAH: summary of loadings from discharges to the City Waterway 7.205

7.6.5 High molecular weight PAH: summary of loadings from discharges to the City Waterway 7.206

7.6.6 Copper: summary of loadings from discharges to the City Waterway 7.230

7.6.7 Zinc: summary of loadings from discharges to the City Waterway 7.231

7.6.8 Lead: summary of loadings from discharges to the City Waterway 7.239

7.7.1 Summary of dredging projects, Ruston-Pt. Defiance Shoreline 7.246

7.7.2 Concentrations of organic compounds with depth in the sediment 7.263

7.7.3 Concentrations of arsenic and metals with depth in the sediment 7.264

7.7.4 Organic compounds: summary of loadings from discharges along the Ruston Shoreline 7.265

7.7.5 Arsenic: summary of loadings from discharges along the Ruston Shoreline 7.267

7.7.6 Cadmium: summary of loadings from discharges along the Ruston Shoreline 7.268

7.7.7 Copper and mercury: summary of loadings from discharges along the Ruston Shoreline 7.269

7.7.8 Lead: summary of loadings from discharges along the Ruston Shoreline 7.270

7.7.9 Zinc: summary of loadings from discharges along the Ruston Shoreline 7.271

8.1 Final ranking of problem areas 8.2

CONTENTS VOLUME 1

Page

LIST OF FIGURES ix

LIST OF TABLES xvi

ACKNOWLEDGEMENTS xxii

1.0 INTRODUCTION 1.1

- 1.1 BACKGROUND 1.1
- 1.2 SITE DESCRIPTION 1.1
- 1.3 NATURE AND EXTENT OF PROBLEM 1.4
- 1.4 COOPERATIVE AGREEMENT 1.6
- 1.5 REPORT OVERVIEW 1.7

2.0 METHODS 2.1

- 2.1 GENERAL APPROACH 2.1
    - 2.1.1 Study Design 2.1
    - 2.1.2 Station Locations 2.1
    - 2.1.3 Data Analysis Methods 2.16
    - 2.1.4 Geophysical Survey 2.18
- 2.2 SEDIMENT CHEMISTRY 2.18
    - 2.2.1 Field Sampling 2.19
    - 2.2.2 Laboratory Analysis for Metals 2.21
    - 2.2.3 Laboratory Analysis for Organic Compounds 2.21
    - 2.2.4 Ancillary Analyses 2.24
- 2.3 WATER COLUMN CHEMISTRY 2.25
    - 2.3.1 Field Sampling 2.25
    - 2.3.2 Laboratory Analysis 2.27
- 2.4 BENTHIC MACROINVERTEBRATES 2.28
    - 2.4.1 Field Sampling 2.28
    - 2.4.2 Laboratory Analysis 2.29

2.5 SEDIMENT BIOASSAYS 2.29

2.5.1 Field Sampling 2.29
2.5.2 Laboratory Analysis 2.29

2.6 FISH HISTOPATHOLOGY 2.32

2.6.1 Field Sampling 2.32
2.6.2 Histopathological Examination 2.33

2.7 BIOACCUMULATION 2.33

2.7.1 Field Sampling 2.33
2.7.2 Laboratory Analysis for Metals 2.34
2.7.3 Laboratory Analysis for Organic Compounds 2.35

2.8 DATA MANAGEMENT 2.36

2.8.1 The Database 2.36
2.8.2 Data Analysis 2.37
2.8.3 Graphics 2.37
2.8.4 Quality Control 2.38
2.8.5 Library 2.38

2.9 HEALTH AND SAFETY 2.38

2.10 SAMPLING AND ANALYSIS QA/QC 2.39

2.10.1 Sample Collection 2.39
2.10.2 Organic Compound Analyses 2.40
2.10.3 Trace Metals and Ancillary Analyses 2.41
2.10.4 Benthic Macroinvertebrates, Sediment Bioassays, and Fish Histopathology 2.41

2.11 RISK ASSESSMENT 2.41

2.11.1 Exposure Evaluation 2.44
2.11.2 Health Effects (Hazard Assessment) Methodology 2.47
2.11.3 Risk Assessment Calculations 2.47

2.12 SOURCE IDENTIFICATION 2.52

2.12.1 Sediment Chemistry 2.52
2.12.2 Water Quality Data 2.57
2.12.3 Point Sources and Runoff 2.57
2.12.4 Groundwater Sources 2.62
2.12.5 Atmospheric Sources 2.63
2.12.6 Spills 2.63
2.12.7 Dredging 2.64

3.0 RESULTS 3.1

3.1 SEDIMENT CHEMISTRY 3.1

3.1.1 Bulk Sediment Characteristics 3.1
3.1.2 Normalization of Chemical Concentrations 3.10
3.1.3 Sediment Metals 3.13
3.1.4 Sediment Organic Compounds 3.20
3.1.5 Prioritization of Areas Based on Sediment Contamination 3.39
3.1.6 Comparison with Historical Conditions 3.69
3.1.7 Contamination of Waterway Suspended Solids 3.72
3.1.8 Summary 3.73

3.2 BENTHIC MACROINVERTEBRATES 3.78

3.2.1 Introduction 3.78
3.2.2 Characteristics of Benthic Communities in Commencement Bay and Carr Inlet 3.78
3.2.3 Comparisons Among Study Areas 3.80
3.2.4 Comparisons Within Study Areas 3.92
3.2.5 Classification Analyses 3.98
3.2.6 Animal-Sediment Relationships 3.106
3.2.7 Indices for Decision Criteria 3.117
3.2.8 Comparisons With Past Studies 3.121
3.2.9 Summary 3.122

3.3 SEDIMENT TOXICITY 3.123

3.3.1 Introduction 3.123
3.3.2 Amphipod Sediment Bioassays 3.125
3.3.3 Oyster Larvae Sediment Bioassays 3.125
3.3.4 Discussion 3.133
3.3.5 Comparison With Historical Data 3.134
3.3.6 Summary 3.140

3.4 FISH ECOLOGY 3.140

3.4.1 Introduction 3.140
3.4.2 Total Fish Assemblages 3.140
3.4.3 English Sole Populations 3.143
3.4.4 Summary 3.151

3.5 FISH HISTOPATHOLOGY 3.153

3.5.1 Introduction 3.153
3.5.2 External Abnormalities 3.153
3.5.3 Classification of Liver Conditions 3.153
3.5.4 Effects of Sex 3.155
3.5.5 Effects of Age 3.157
3.5.6 Spatial Patterns of Individual Disorders 3.157
3.5.7 Spatial Patterns of Fish Having One or More Major Lesion 3.162
3.5.8 Fish Condition Comparisons 3.164

3.5.9 Comparisons With Historical Data 3.164
3.5.10 Summary 3.169

3.6 BIOACCUMULATION 3.170

3.6.1 Introduction 3.170
3.6.2 Metals in Fish Muscle 3.172
3.6.3 Metals in Crab Muscle 3.174
3.6.4 Organic Compounds in Fish Muscle 3.174
3.6.5 Organic Compounds in Crab Muscle 3.193
3.6.6 Comparison With Other Studies 3.195
3.6.7 Summary 3.200

4.0 CONTAMINANT, TOXICITY, AND BIOLOGICAL EFFECTS RELATIONSHIPS 4.1

4.1 INTRODUCTION 4.1

4.2 RELATIONSHIPS AMONG CONTAMINANTS, TOXICITY, AND BENTHIC EFFECTS 4.1

4.2.1 Correlation of Indicators 4.2
4.2.2 Apparent Chemical Effect Thresholds 4.3
4.2.3 Correspondence Among Chemical, Toxicity, and Benthic Effects Gradients 4.21
4.2.4 Summary 4.29

4.3 COMPARISON OF BIOASSAY RESPONSES WITH BENTHIC INVERTEBRATE ASSEMBLAGES 4.34

4.3.1 Correlation of Indicators 4.35
4.3.2 Comparison of Bioassays with Benthic Groupings 4.35
4.3.3 Comparison of Significant Responses 4.35
4.3.4 Summary 4.38

4.4 COMPARISONS OF LESION PREVALENCES IN ENGLISH SOLE WITH CHEMICAL CONTAMINANTS IN SEDIMENTS 4.38

4.5 RELATIONSHIP BETWEEN BIOACCUMULATION AND SEDIMENT CONTAMINATION 4.42

4.5.1 Inorganic Substances 4.43
4.5.2 Organic Substances 4.45
4.5.3 Summary 4.48

4.6 RELATIONSHIP BETWEEN BIOACCUMULATION AND FISH HISTOPATHOLOGY 4.48

4.6.1 Inorganic Substances 4.48
4.6.2 Organic Substances 4.50
4.6.3 Summary 4.52

5.0 PUBLIC HEALTH ASSESSMENT 5.1

5.1 INTRODUCTION 5.1

5.2 SUMMARY OF RESULTS 5.1

- 5.2.1 Carcinogens in Fish Muscle Tissue 5.2
- 5.2.2 Noncarcinogens in Fish Muscle Tissue 5.4
- 5.2.3 Carcinogens in Crab Muscle Tissue 5.4
- 5.2.4 Noncarcinogens in Crab Muscle Tissue 5.6
- 5.2.5 Consumption of Fish Livers 5.6

6.0 PRIORITIZATION OF PROBLEM AREAS AND CONTAMINANTS 6.1

6.1 INTRODUCTION 6.1

6.2 IDENTIFICATION OF PROBLEM AREAS 6.1

- 6.2.1 Action Assessment Matrices 6.1
- 6.2.2 Application of Action Levels to Determine Problem Areas 6.11
- 6.2.3 Ranking of Study Areas and Segments 6.11

6.3 SPATIAL EXTENT AND RANKING OF PROBLEM AREAS 6.19

6.4 CHEMICAL CHARACTERIZATION OF PROBLEM AREAS 6.25

- 6.4.1 Hylebos Waterway 6.26
- 6.4.2 Blair Waterway 6.27
- 6.4.3 Sitcum Waterway 6.28
- 6.4.4 Milwaukee Waterway 6.28
- 6.4.5 St. Paul Waterway 6.28
- 6.4.6 Middle Waterway 6.29
- 6.4.7 City Waterway 6.29
- 6.4.8 Ruston-Pt. Defiance Shoreline 6.30

6.5 RANKING OF POTENTIAL PROBLEM CHEMICALS IN PROBLEM AREAS 6.31

6.6 SUMMARY 6.37

7.0 SOURCE EVALUATIONS

7.1 INTRODUCTION

Results of Task 4 of the Commencement Bay Nearshore/Tideflats Remedial Investigation are presented in Section 7. The primary goal of Task 4 was to determine major sources of contaminants observed in the surficial sediments of the nearshore/tideflats area. This was a difficult task given the extensive industrial development of the Tacoma area over the past century. Throughout this period, Commencement Bay and associated waterways have received contaminants from a multitude of discharges, many of which, until recently, have been unregulated. Even today, major discharges are not routinely monitored or regulated for many of the contaminants identified to be of concern in these investigations.

The nearshore/tideflats area of Commencement Bay has been more intensively sampled than any other in Puget Sound. Therefore, a large database was available on potential contaminant sources and observed contaminant levels in water and sediment. Ancillary information was also available. Some of the most valuable information utilized in source identification included:

- Spatial gradients of contamination in surficial sediments - The spatial gradient of sediment contamination was the most important component of source identification. It was used to establish the probable location of the contaminant source, with the implicit assumption that the most contaminated sediments were closest to the source.

- Vertical gradients of contamination in sediment cores - This information was used to determine the history of contaminant input. Correlations between sediment concentrations and historical land use information were used to identify past sources of contamination.

- Analyses for the contaminant in discharges - Effluents from many point and nonpoint sources in the nearshore/tideflats area have been analyzed for some of the contaminants of concern. This information was used to identify potential sources, to determine if known sources could account for the contaminant levels seen in the sediments, and to calculate mass loading by which sources could be ranked.

- Dredging history - Knowledge of past dredging activities was valuable in interpreting patterns of contamination seen in surficial and subsurface sediments.

- Environmental fate processes - Information on environmental fate process (e.g., solubility, sorption, volatilization, degradation) of the various contaminants was valuable in placing constraints on the timing or route of contaminant migration.

- Industrial activities - When the spatial gradient of contamination suggested a specific property as the contaminant source, past and present industrial activities at the site were reviewed to confirm responsibility. This review included period of operation, raw materials, manufacturing processes, potential by-products, waste disposal practices, past spills, and the history of enforcement actions.

Source identifications were attempted for preliminary contaminants of concern in problem areas defined on the basis of significant chemical, toxicity, and biological indicators. The twelve priority problem areas for which source identifications were conducted are shown in Figure 7.1.1. A preliminary, incomplete set of contaminants was defined for these investigations because project time constraints required source evaluations to begin several months before all data analyses in Task 3 investigations were completed. Contaminants designated on a preliminary basis for these source evaluations are summarized in Figure 7.1.1 for each problem area.

The preliminary list of contaminants in Figure 7.1.1 was based on chemicals with concentrations that exceeded 80 percent of all sediment concentrations in the Commencement Bay study area at more than one station in a problem area. Because of the large number of source identifications required using this guideline, not all chemicals present above the 80th percentile level were included on the preliminary list for source identification. Contaminants exceeding the 80th percentile concentration cutoff were excluded from the preliminary list when their spatial distributions were clearly unrelated to the observed pattern of toxicity or biological effects in a problem area, or when there were several other chemicals with clearer relationships. Chemicals present below the 80th percentile concentration in a problem area were included on the preliminary list if there was a concern for potential biological effects in the corresponding waterway (e.g., elevated benzyl alcohol concentrations in abnormal fish livers or PCBs in fish muscle tissue).

Chemicals found in high concentration only in historically sampled sediments in a problem area were not always included in the preliminary list of potential problem chemicals because these data sets had not yet been fully incorporated into the data analysis (in some cases, these data were not received from the contributing agencies until after source evaluations had begun). Chemicals later determined to have the highest priority for source evaluation were already on the preliminary list of potential problem chemicals. These chemicals were present above an Apparent Effect Threshold (AET) in a problem area and had concentration gradients that corresponded with observed toxicity or benthic effects as discussed in Section 6 (Volume I). Most chemicals determined in Section 6 as having the second highest priority for source evaluation were also already on the preliminary list of potential problem chemicals. These second priority contaminants were defined as those with concentrations above an AET at more than one station within a problem area, but either their concentration gradient did not correspond with observed toxicity or benthic effects, or there were insufficient data to evaluate the relationships. Priority chemicals that had not been

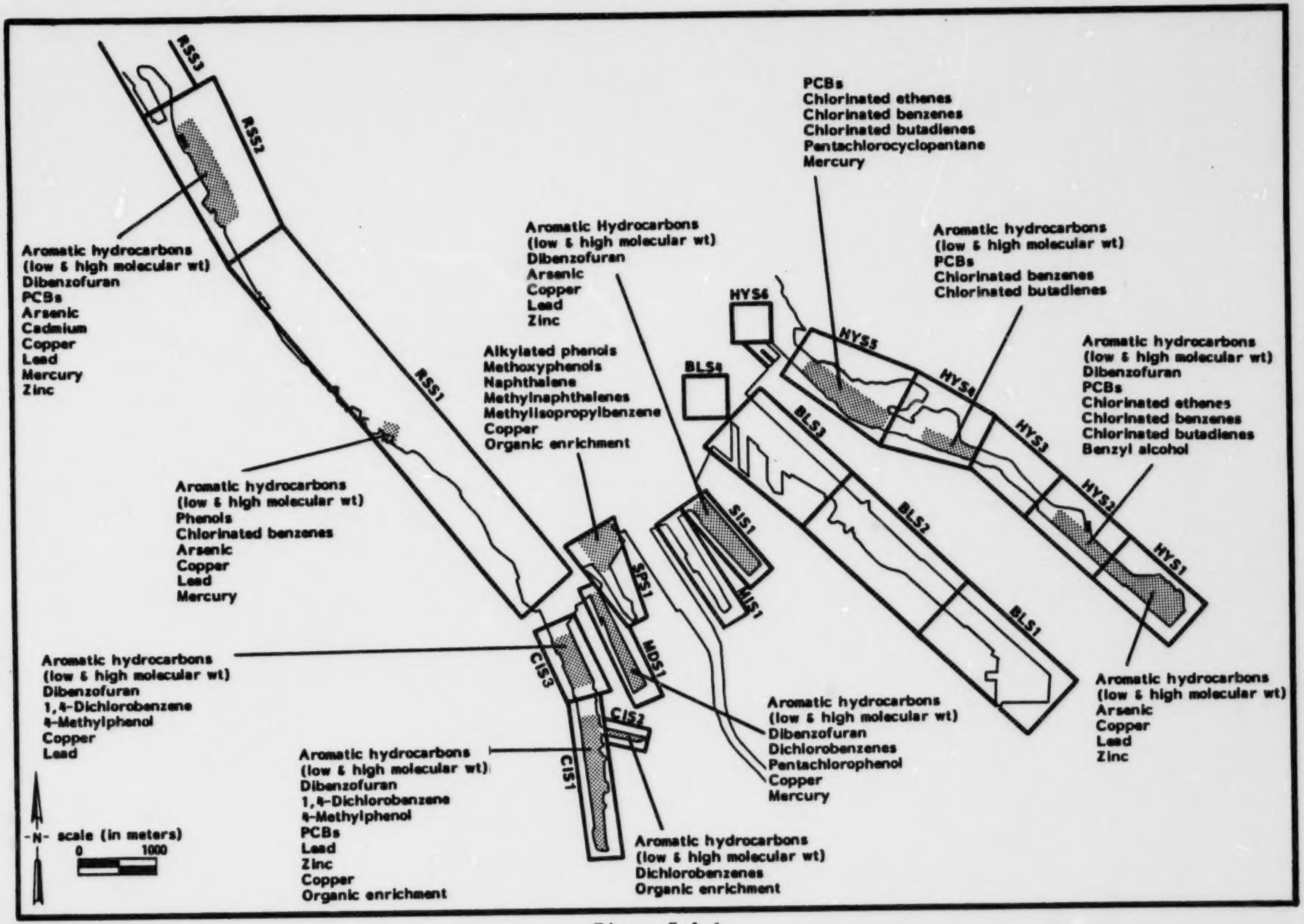


Figure 7.1.1

PROBLEM AREAS (SHADED) AND THEIR RESPECTIVE CONTAMINANTS OF CONCERN FOR WHICH SOURCE IDENTIFICATION HAS BEEN PURSUED subjected to source evaluation as preliminary contaminants of concern are summarized at the beginning of each major section. A complete list of priority chemicals in each problem area is given in Table 6.14 in Section 6. For ease of comparison, AET for different chemicals are noted on spatial and depth plots of contaminant concentrations.

The remainder of Section 7.0 is directed towards identifying potentially responsible sources for each preliminary contaminant of concern within each problem area shown on Figure 7.1.1. For each potential source that is identified, the following additional information is provided, if available:

- Characterization of the source as historical or ongoing
- Potential routes of contaminant migration
- Ranking of the source relative to others in the problem area, if permitted by the mass loading estimates
- Ongoing remedial actions, if any
- Data gaps
- Recommendations for source control and, if possible, a statement on the effectiveness of this control in improving sediment quality.

The results are presented in the following order: Section 7.2 - Hylebos Waterway; 7.3 - Sitcum Waterway; 7.4 - St. Paul Waterway; 7.5 - Middle Waterway; 7.6 - City Waterway; and 7.7 - Ruston-Pt. Defiance Shoreline. Metal concentration data normalized to percent fine-grained material are presented only when additional trends apparent in the dry-weight data are observed. These normalizations are not used in the discussion of Hylebos Waterway because the required grain size data are missing for key samples.

7.2 HYLEBOS WATERWAY

7.2.1 Introduction

7.2.1.1 Industrial Development--

Hylebos Waterway was formed by dredging the Puyallup River delta in the early 1920s. Since that time, its shoreline has become heavily industrialized (Figure 7.2.1). Among the first industries established along Hylebos Waterway were Occidental Chemical Corporation (previously Hooker Chemical and Plastics Corporation) and Pennwalt Corporation (previously Pennsylvania Salt Manufacturing Company). These industries began operations along Hylebos Waterway in the 1920s to provide chlorine for local pulp and paper industries. In the past, they produced a variety of inorganic compounds (e.g., sodium hypochlorite and caustic soda) and continue to do so. Schaffer Box and Pulp operated along the south shore of the waterway from 1924 to 1932. As a result of discharge of their sulfite waste liquor, they have been implicated as a major source of pollution during that time (Dames and Moore 1982).

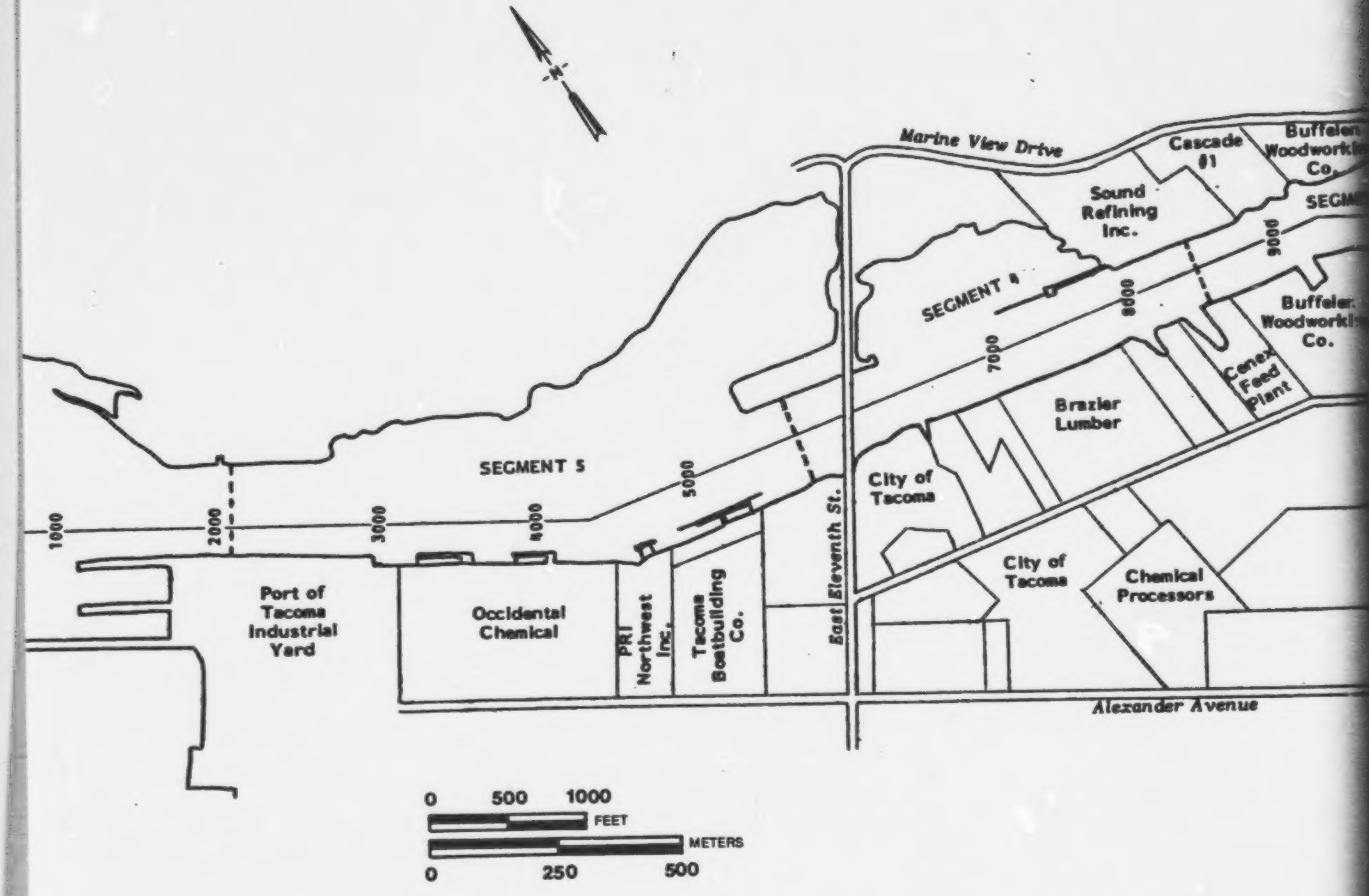
Two smelting industries were established along upper Hylebos Waterway in the early 1940s. Ohio Ferro Alloys was built in 1942 for the production of chrome, and later silicate and ferrosilicate, on the site of what is now Cascade Timber Yard #2. The plant closed in 1972 and has since been razed (Dames and Moore 1982). In 1941-42, Kalunite Inc./Oline Co. opened an aluminum smelting plant on the site of what is now Kaiser Aluminum and Chemical Corporation, which took over operation of the plant in 1949.

Industrial development along the north shore of Hylebos Waterway has not been as extensive as that along the south shore, due principally to the limited land area available between the waterway and the steep bluffs. The three largest industries along the north shore are Sound Refining, General Metals, and Tacoma Boatbuilding. All three were established at their present location in the late 1960s to mid-1970s.

A notable feature of Hylebos Waterway is the numerous log sorting yards along its shoreline. Log sorting yards occupy nearly all of the southern shoreline of the upper waterway and several areas throughout the middle portion of the waterway. ASARCO slag has been used as ballast in most of these yards and surface water runoff from the yards has been found to contain high concentrations of metals (Norton and Johnson 1985a).

7.2.1.2 Discharges--

Locations of all discharges to Hylebos Waterway that are noted in the text are shown in Figure 7.2.2. The common names for these discharges are given when available. Several of the discharges are regulated and are authorized discharges through the National Pollutant Discharge Elimination System (NPDES) permit program. Four of the permitted discharges have been classified as major industrial discharges: Occidental Chemical Corporation, Pennwalt Corporation, Kaiser Aluminum and Chemical Corporation, and



Fig

MAJOR INDUSTRIES SURROU
FROM PORT OF TACOMA - SUMMARY OF PO

A

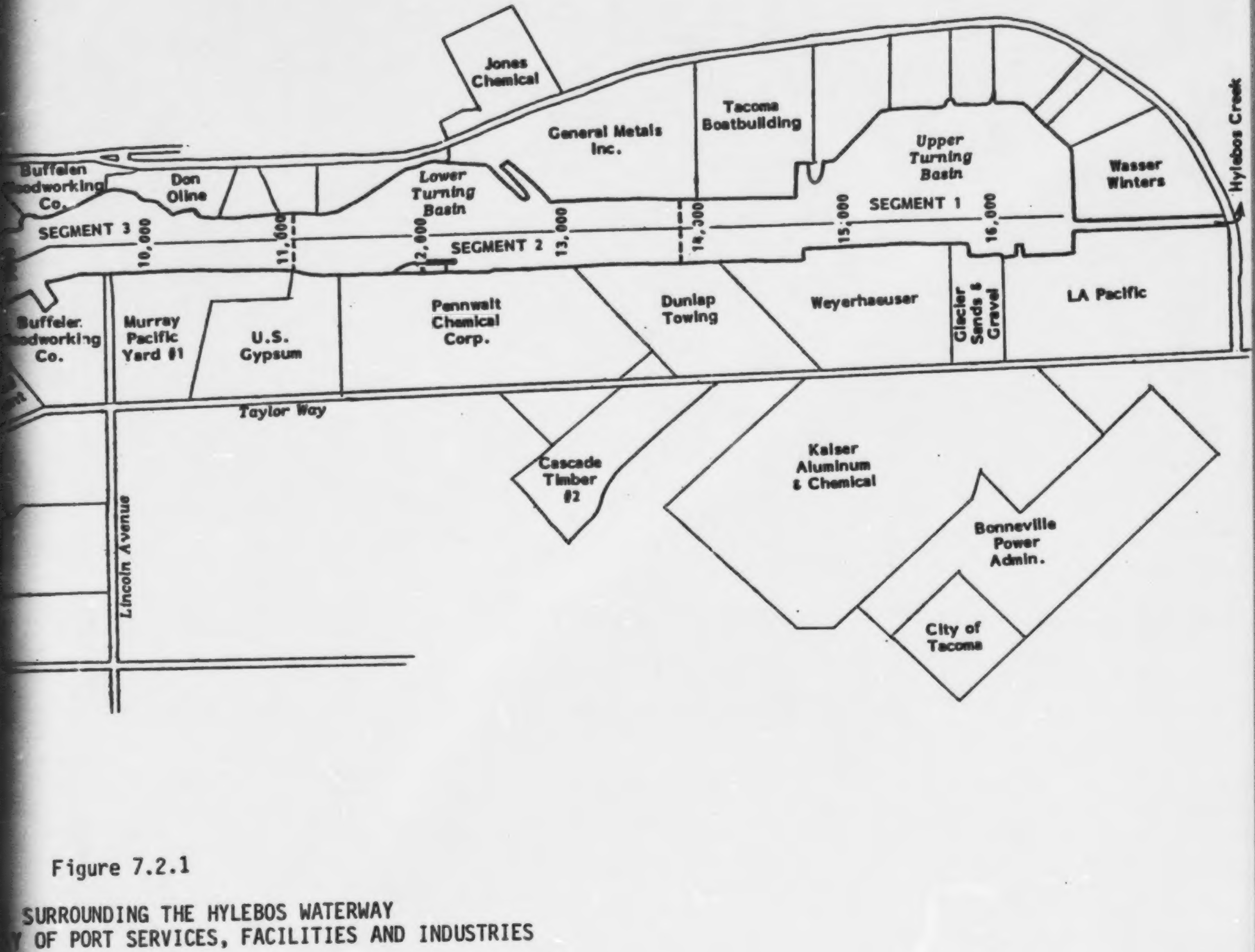


Figure 7.2.1

SURROUNDING THE HYLEBOS WATERWAY
Y OF PORT SERVICES, FACILITIES AND INDUSTRIES

B

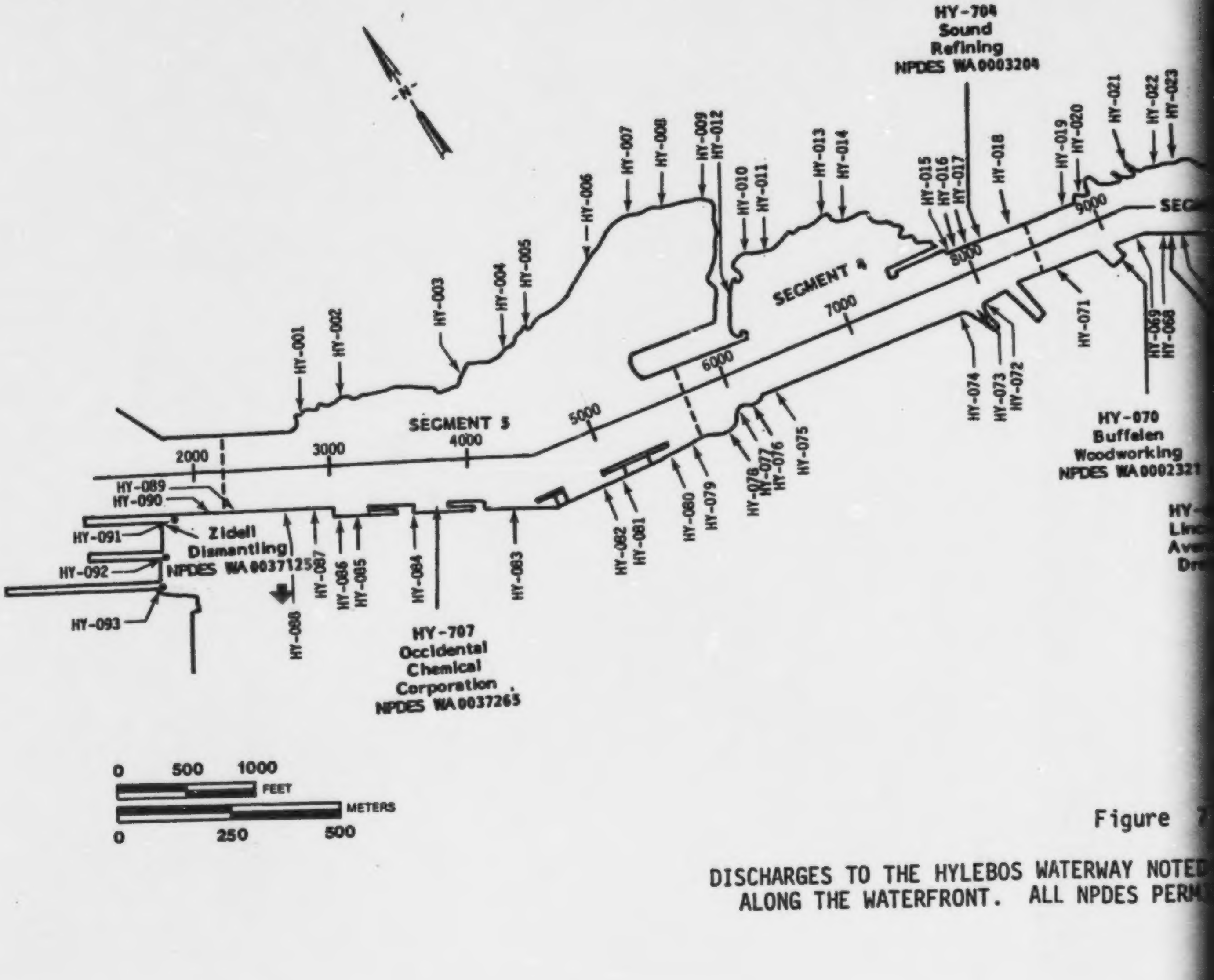


Figure 7

DISCHARGES TO THE HYLEBOS WATERWAY NOTED
ALONG THE WATERFRONT. ALL NPDES PERM

A

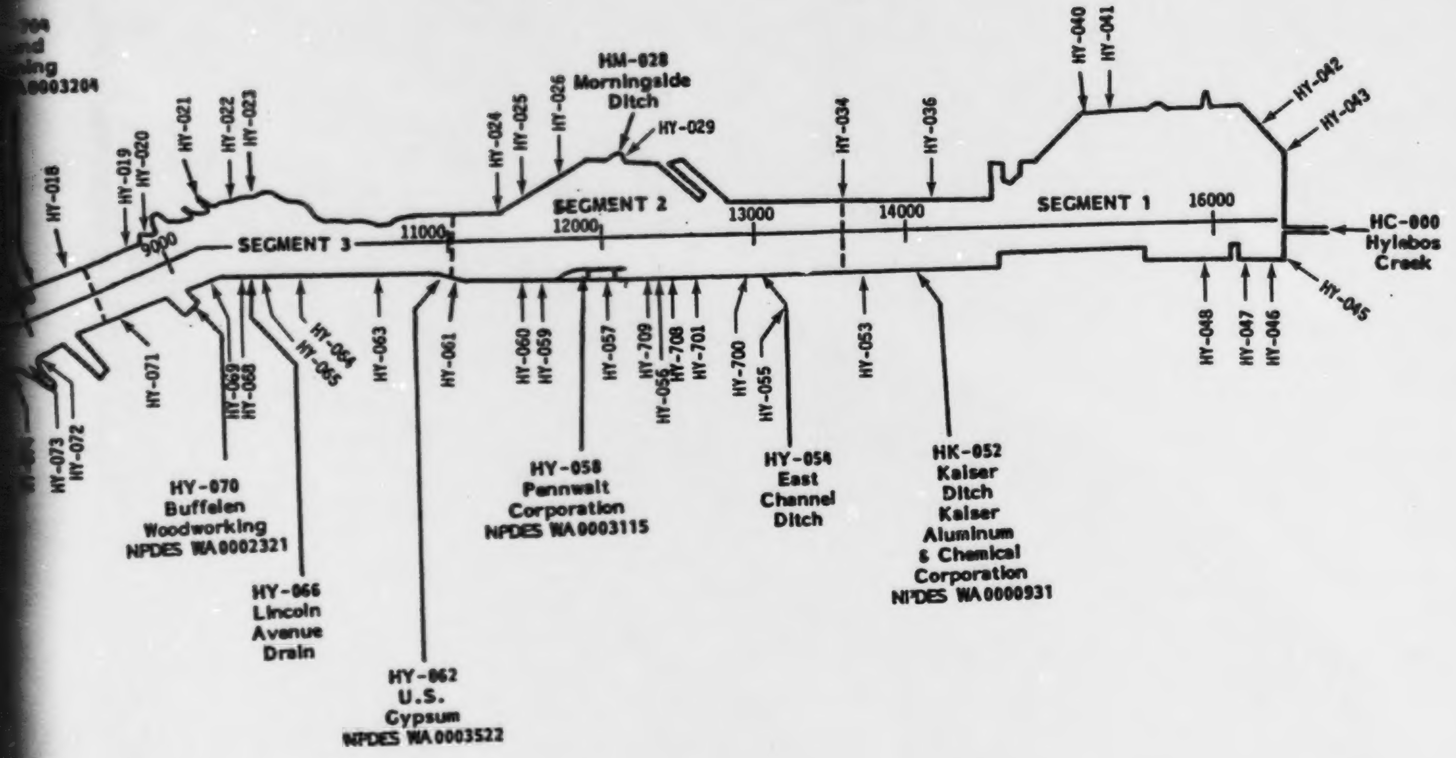


Figure 7.2.2

LEBOS WATERWAY NOTED IN THE TEXT AND THEIR LOCATIONS
NT. ALL NPDES PERMITTED DISCHARGES ARE INDICATED

B

Sound Refining. Three minor NPDES-permitted discharges are located on Hylebos Waterway: Zidell Dismantling, Buffelen Woodworking, and U.S. Gypsum. NPDES permit effluent discharge limits for these industries typically do not limit the contaminants discussed in this report. The only contaminant of concern specifically regulated through the permit limits of dischargers is lead (at Pennwalt and Occidental Chemical Corporations). Annual monitoring of zinc, copper, iron, and nickel are also required at Occidental Chemical Corporation.

7.2.1.3 Dredging History--

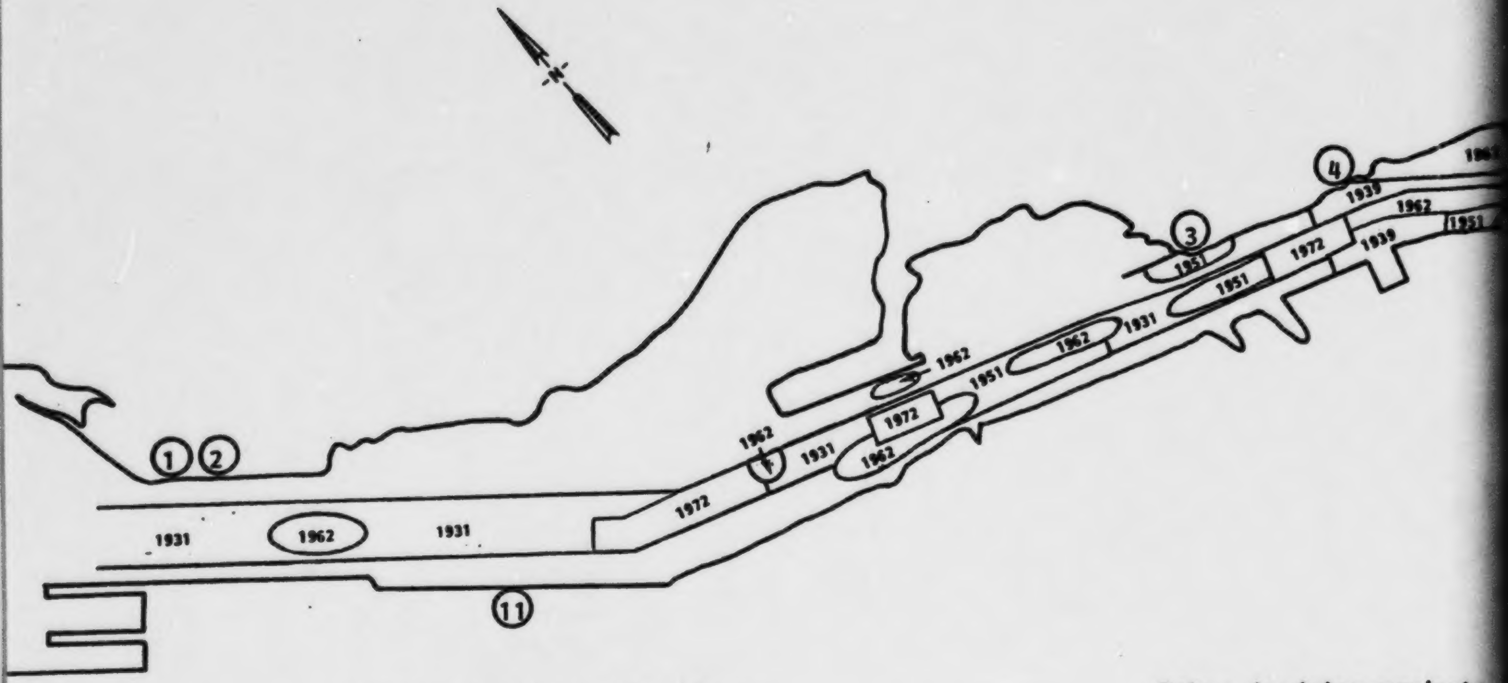
Dredging by the Port of Tacoma and the U.S. Army Corps of Engineers has changed the shape and size of Hylebos Waterway over the years (Figure 7.2.3). When the waterway was created in the 1920s, it extended only to the point of what is now the lower turning basin, approximately 12,000 ft from the mouth of the waterway. Channel deepening and some shoreline modification resulted from dredging activities in 1931, 1934, 1939, 1945, and 1951 (Dames and Moore 1982). In 1954-1955, the Port of Tacoma extended the waterway 3,800 ft (Johnston 1981). Subsequent dredging by the Corps of Engineers in 1958, 1962, and 1964-1966 widened the upper waterway and created the upper turning basin (Dames and Moore 1982). The most recent maintenance dredging, which occurred in 1972, was confined to the upper turning basin and three areas in the general vicinity of the 11th Street bridge (Landau 1984). Since 1972, the only dredging in the waterway has been performed by specific industries along the waterfront.

7.2.2 Contaminants of Concern

Locations of sediment chemistry stations in Hylebos Waterway sampled as part of the present investigation and all historical sampling sites are shown in Figure 7.2.4. Hylebos Waterway has been divided into six segments. Nine contaminants or groups of contaminants are listed in Figure 7.2.1 as preliminary contaminants of concern:

Organic Compounds	Metals
Pentachlorocyclopentane isomer (Segment 5)	Arsenic (Segments 1,2)
Polychlorinated biphenyls (PCBs) (Segments 2,4,5)	Copper (Segments 1,2)
Aromatic hydrocarbons (Segments 1,2,4)	Lead (Segments 1,2)
Dibenzofuran (Segment 2)	Zinc (Segments 1,2)
Benzyl alcohol (Segment 2)	Mercury (Segments 2,5)
Chlorinated hydrocarbons (Segments 2,4,5) (i.e., ethenes, benzenes, and butadienes)	

Concentrations of the substances listed above as of preliminary concern were later determined to exceed benthic or toxicity AET (dry weight) in their respective areas, except dibenzofuran. Concentrations of dibenzofuran exceeded toxicity AET after normalization to percent fine-grained material in Segment 4 (Station HY-46). Concentrations of several of these substances exceeded AET (dry weight) in other areas than those listed. However, the entire waterway distribution of these contaminants is typically considered



Corps of Engineers Dredging

Year	Quantity (cu. yds.)
1931	645,000
1934	102,000
1939	761,000
1945	46,000
1951	167,000
1958	17,000
1962	376,000
1964-66	1,778,000
1972	109,000

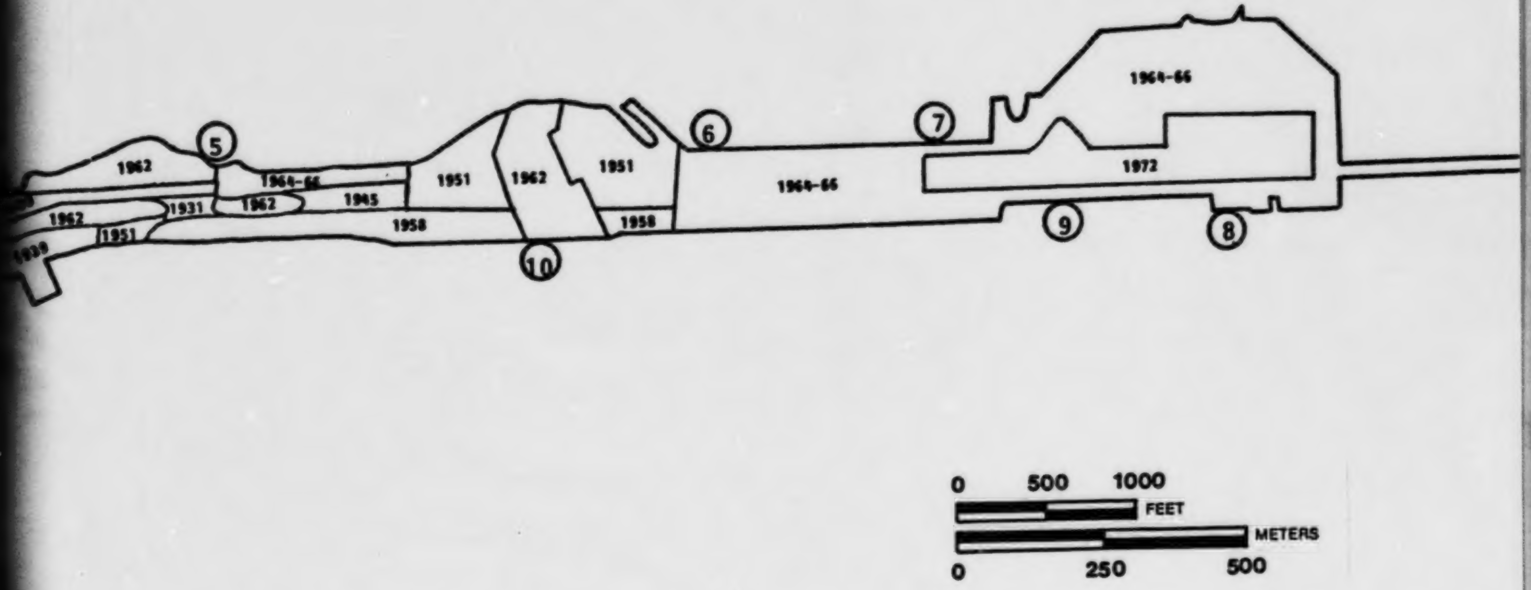
Other dredging projects

Map #	Permittee
	Port of Tacoma
1	Commencement Bay Marina
2	Donald S. Olson
3	Sound Refining
3	Sound Refining
3	Sound Refining
4	Cascade Pole
5	Marine Technical Services
6	General Metals
6	General Metals
6	General Metals
6	General Metals

Figure

DREDGING ACTIVITY IN TH
Location of Corps of Engineers
from sketches obtained from D.
recent dredging shown in any g
activities determined by revie
applications, 1967-1984.

A



projects		
	Year	Quantity (cu. yds.)
	1954-55	unk.
arina	1981	8,000
	1976-78	250
	1967	23,600
	1970-71	9,000
	1975	95,000
	1973	1,100
rvices	1980	1,000
	1972	4,100
	1974-75	5,000
	1979	2,000
	1984	3,000

Other dredging projects

Map #	Permittee	Year	Quantity (cu. yds.)
7	Tacoma Boat Building	1976	2,500
8	Glacier Sand & Gravel	1973	600
8	Glacier Sand & Gravel	1982	3,000
9	Weyerhaeuser	1970	20,000
9	Weyerhaeuser	1970	600
9	Weyerhaeuser	1972	35,000
9	Weyerhaeuser	1972	1,500
9	Weyerhaeuser	1976	4,100
9	Weyerhaeuser	1982	600
10	Pennwalt Corp.	1982	600
11	Occidental Chem. Corp.	1967-68	15,500
11	Occidental Chem. Corp.	1974	10,600

Figure 7.2.3

VITY IN THE HYLEBOS WATERWAY
Engineers dredging projects estimated
d from D. Karna, EPA. Only the most
in any given area. Private dredging
by review of COE dredging permit
84.

B

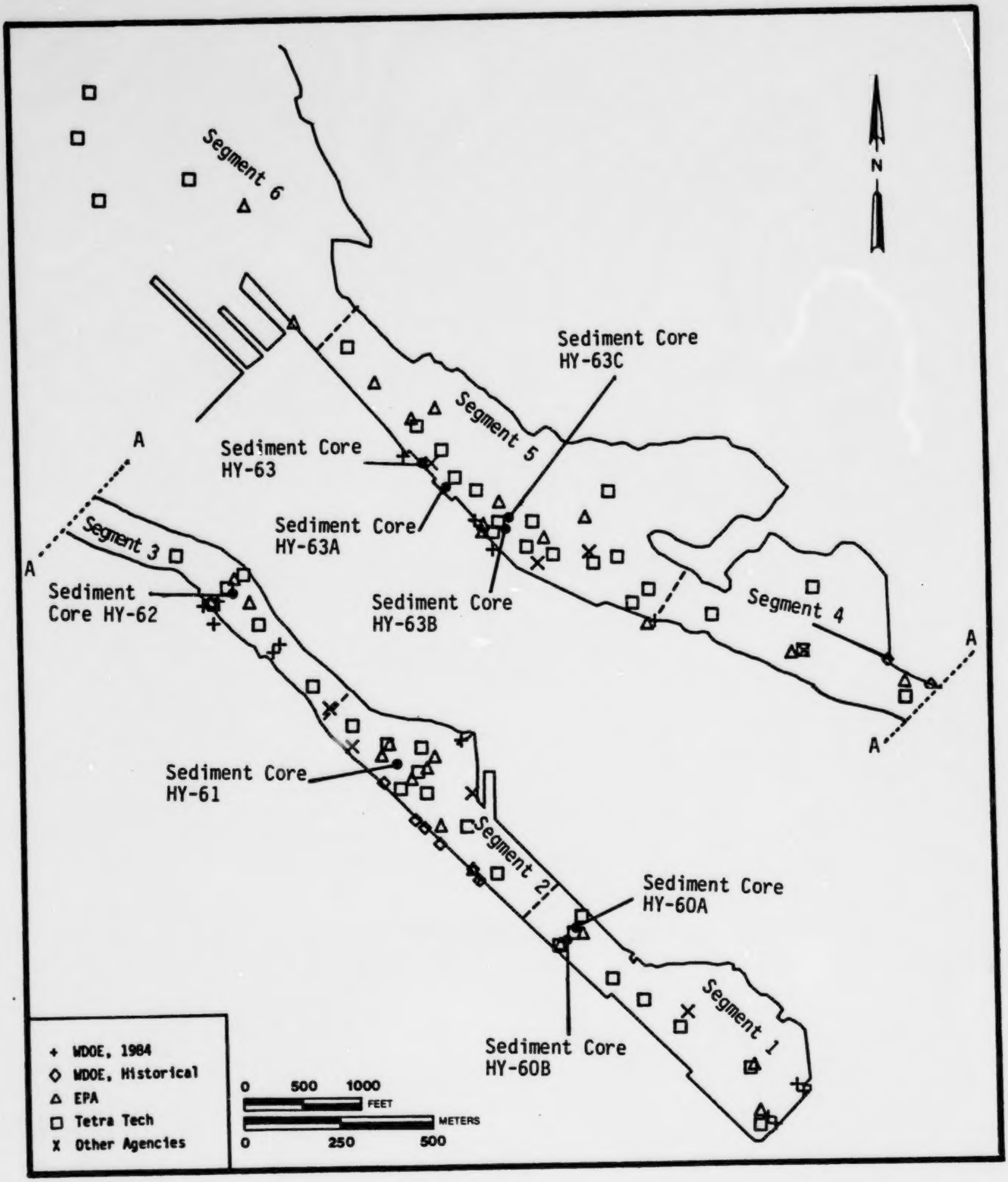


Figure 7.2.4

SURFICIAL SEDIMENT STATIONS AND SEDIMENT CORE LOCATIONS FROM ALL HYLEBOS WATERWAY STUDIES IN THE PROJECT DATA BASE during source evaluations in any one area. Other contaminants with concentrations that were ultimately determined to exceed AET but were not subjected to source evaluations include:

Substance	Station Where AET (DW) Exceeded
Phenol	HY-01, HY-12, HY-16, HY-22, HY-36
Phthalate esters	HY-12, HY-22
N-nitrosodiphenylamine	HY-31, HY-33
Antimony	HY-16, HY-19 (and intertidal sediments)
Nickel	HY-22, HY-23 (and intertidal sediments)

Tentatively identified compounds for which concentrations also exceeded AET but were not evaluated for sources included: 1-methyl(2-methylethyl)-benzene, biphenyl, dibenzothiophene, methylphenanthrenes, methylpyrenes]. All of these tentatively identified compounds likely share common sources with the PAH. These substances are not discussed further.

The simplified distribution of each preliminary contaminant of concern in the surficial sediments of Hylebos Waterway is presented in Figure 7.2.5. Distributions are based on data from Tetra Tech sampling events and all historical studies. Compounds elevated above the bay-wide 90th percentile concentration that have not been designated as preliminary contaminants of concern are also shown in Figure 7.2.5. For example, copper concentrations are elevated above the 90th percentile in Segment 5, but copper is not a contaminant of concern in Segment 5. Copper is a contaminant of concern in Segments 1 and 2 and is elevated above the 90th percentile in those segments. Figure 7.2.5 is presented to show the most contaminated areas of the waterway and to show parallels among the distributions of the contaminants, since contaminants with similar distributions may have common sources. The areas of elevated contaminant concentrations are indicated by lines. The fine lines indicate areas in which the concentration of the contaminant exceeded the 80th percentile of that contaminant's concentrations in all Tetra Tech stations or August, 1984, Port of Tacoma stations throughout the nearshore/tideflats study area. The heavy lines indicate areas that exceeded the 90th percentile of the concentrations in samples from these stations. Areas of high concentration may not coincide with areas of concern for each contaminant, since the latter reflects biological as well as chemical data.

Four trends are apparent from Figure 7.2.5:

- Hylebos Waterway Segments 2 and 5 had the greatest number of contaminants with concentrations exceeding the 80th and 90th percentile.

- The sediments near the mouth of the waterway (Segment 6) were relatively uncontaminated.

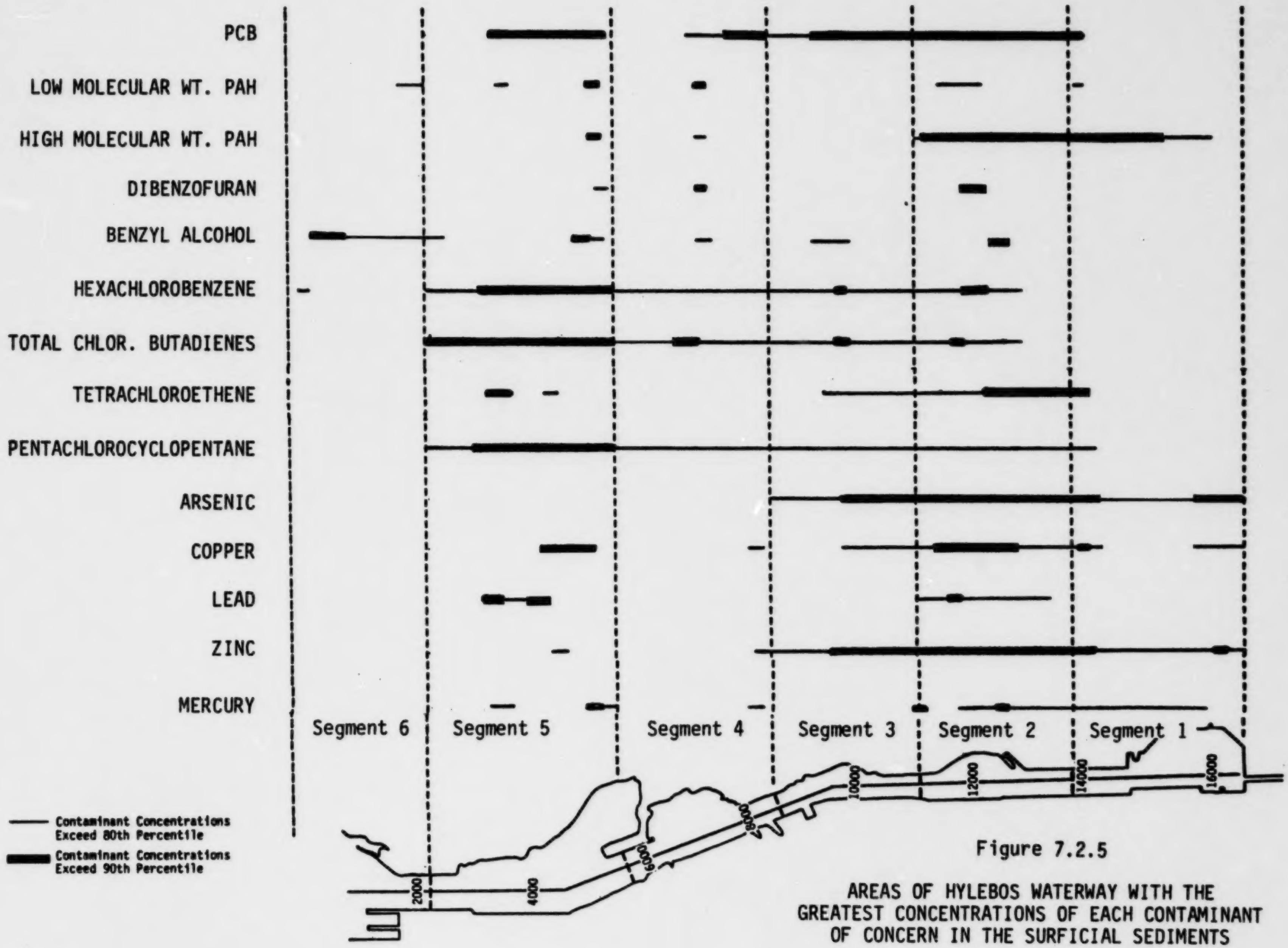


Figure 7.2.5

AREAS OF HYLEBOS WATERWAY WITH THE GREATEST CONCENTRATIONS OF EACH CONTAMINANT OF CONCERN IN THE SURFICIAL SEDIMENTS

- Segment 5 was characterized by elevated concentrations of most of the identified chlorinated organic compounds (hexachlorobenzene, chlorinated butadienes, a pentachlorocyclopentane isomer, tetrachloroethene, and PCBs).

- Since a similar pattern of contamination was seen for hexachlorobenzene, the chlorinated butadienes, and the pentachlorocyclopentane isomer, common sources may be responsible. A mass of unidentified chlorinated compounds is characteristic of Hylebos Waterway; the reported compounds represent only a small fraction of this class of compounds.

Average mass flux estimates were calculated for chlorinated benzenes, chlorinated butadienes, chlorinated ethenes, arsenic, copper, lead, and zinc to enable a comparison of mass loadings of these contaminants relative to their sediment concentrations in Hylebos Waterway. Insufficient source data were available to calculate mass flux estimates for the other priority contaminants. The mass flux estimates were evaluated using average concentrations of the contaminants in sediments from all present and historical stations according to the procedures and criteria outlined in Section 2.12.3.2. All of the source-derived mass fluxes were within an order of magnitude of the concentration-derived mass fluxes with the exception of chlorinated benzenes and chlorinated ethenes. Therefore, according to the uncertainty criteria for this analysis, no data gaps were indicated in accounting for major sources of chlorinated butadienes, arsenic, copper, lead, or zinc. The source-derived mass flux for chlorinated ethenes and benzenes was less than 0.1 to 1 percent of the concentration-derived mass flux. A data gap in the identification of sources of these chlorinated compounds is indicated.

In the following sections, each contaminant (or contaminant group) of concern is addressed individually. Its spatial distribution within the waterway sediments is discussed, contaminant loadings from known sources are calculated, and all known or potential sources are evaluated.

7.2.3 Polychlorinated Biphenyls

7.2.3.1 Spatial Distribution--

PCB concentrations were highly variable in Hylebos Waterway sediments. (Figure 7.2.6). Concentrations were consistently below 200 ug/kg in Segment 1 at the head of the waterway. Maximum PCB concentrations exceeded 1,000 ug/kg in all other segments. This patchy distribution remained after concentrations were normalized to organic carbon, suggesting that PCBs in Hylebos Waterway do not come from the major carbon sources in the waterway (e.g., Kaiser Ditch, silt from the Puyallup River; see Section 3.1.1.3), but from multiple local sources.

The highest PCB concentrations (dry weight) in Hylebos Waterway Segment 5 were restricted to the southern shore of the waterway (Figure 7.2.7). With increasing distance from shore, PCB concentrations dropped off abruptly. The same pattern was evident when concentrations were normalized to total

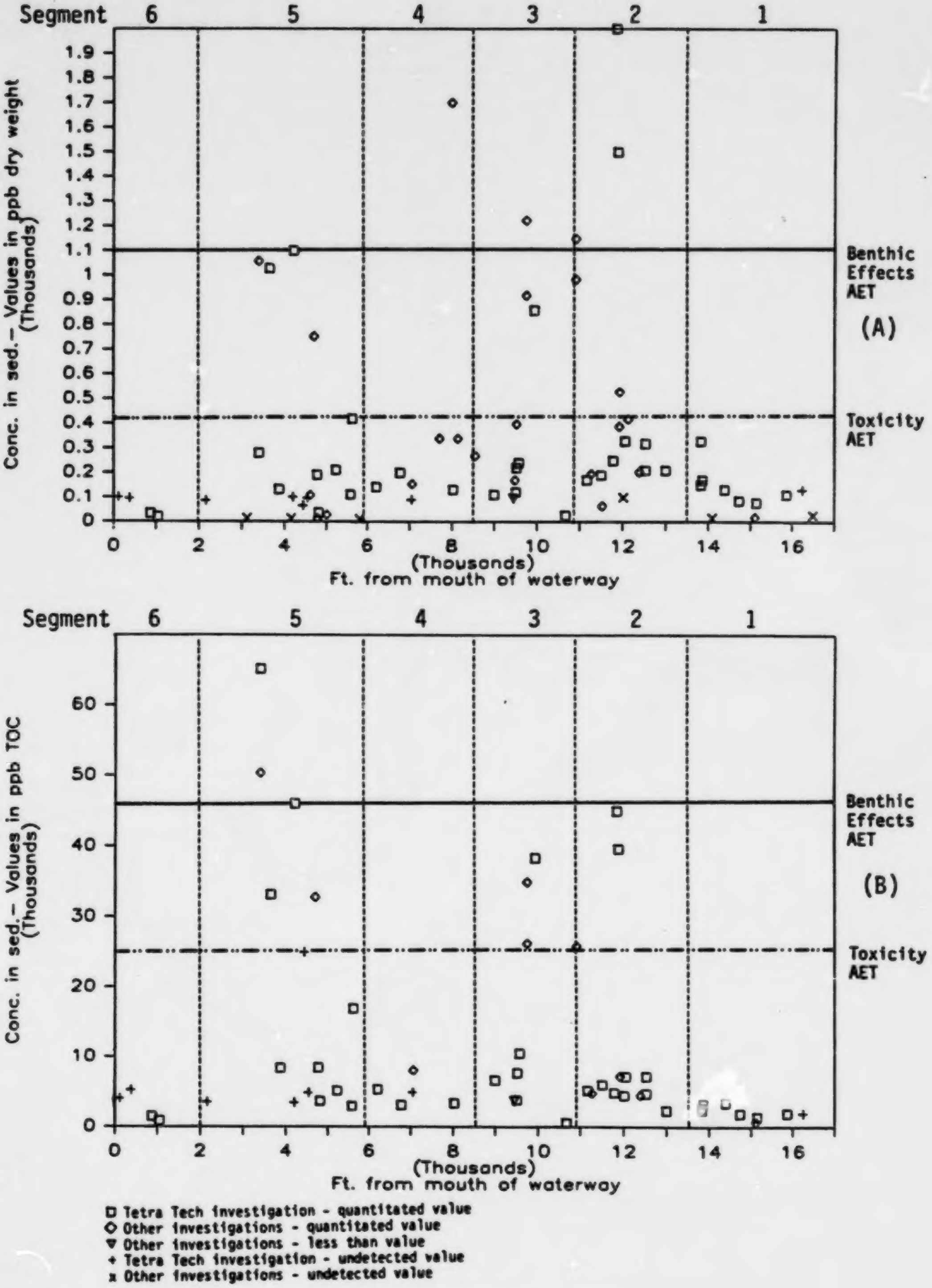


Figure 7.2.6

CONCENTRATIONS OF TOTAL PCBs IN THE SURFICIAL SEDIMENTS OF THE HYLEBOS WATERWAY WITH DISTANCE FROM THE MOUTH OF THE WATERWAY
(A) Concentrations on a dry weight basis
(B) Concentrations normalized to total organic carbon content of the sediments

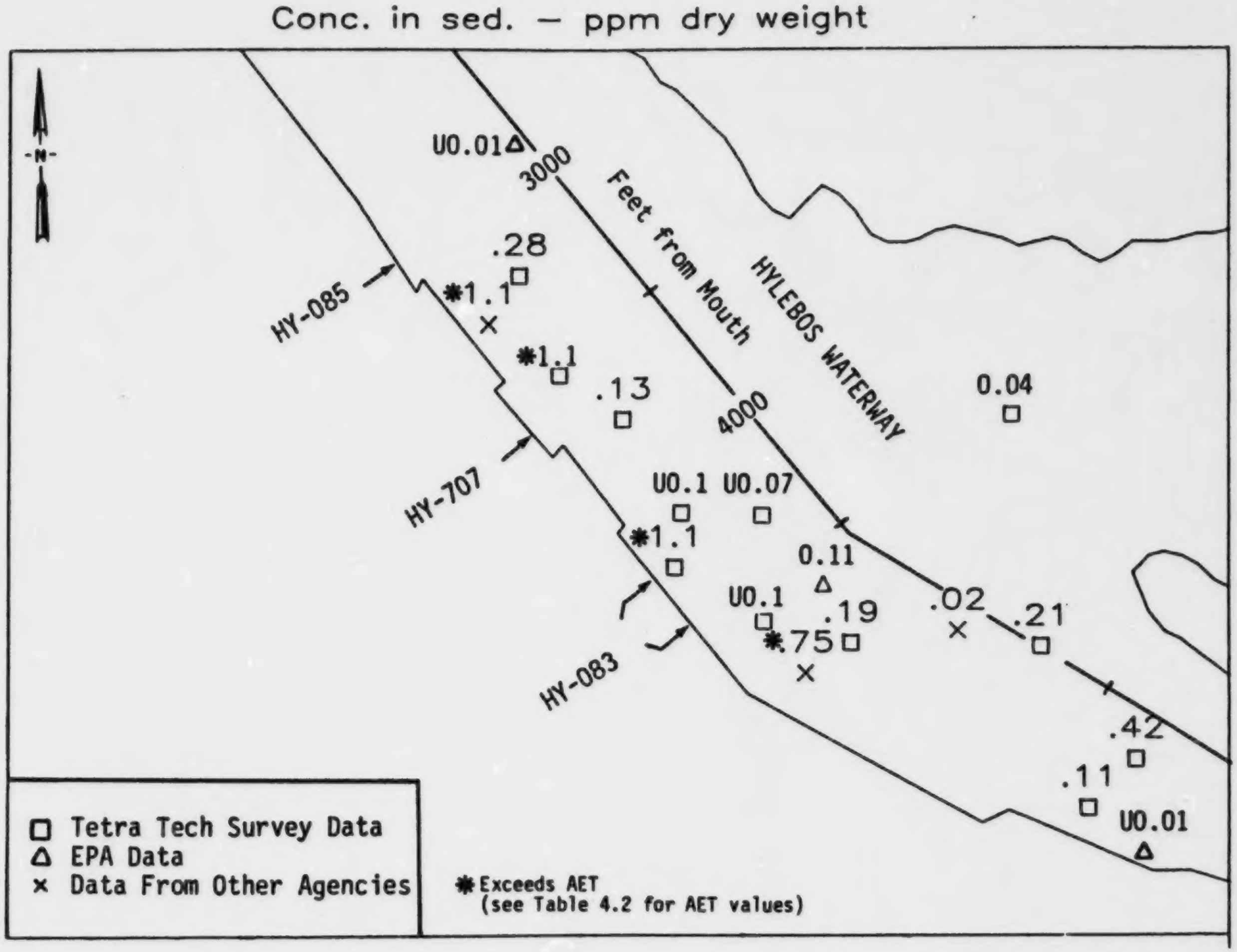


Figure 7.2.7

CONCENTRATIONS OF TOTAL PCBs IN THE SURFICIAL SEDIMENTS OF THE HYLEBOS WATERWAY SEGMENT 5

U = undetected with the detection limit shown organic carbon content. The extent of the contaminated zone along the length of the waterway cannot be clearly defined because of the absence of data to the west of Station HY-46 (280 ug/kg). However, the contamination extended at least 1,500 ft along the waterfront. The spatial gradient indicates that the source of PCB contamination is along the southern shore of the waterway.

PCB concentrations in sediment cores from Hylebos Waterway Segment 5 (Figure 7.2.8) peaked at depth in the sediment column. (Four core samples were taken in this area, but only two are shown. PCB detection limits for the other two cores exceeded 1,000 ug/kg for several of the horizons.) Although the depth of the subsurface maximum varied among samples, the contamination extended to at least 0.4 m depth. At core Stations HY-63-B and HY-63-C, decreasing concentrations in the upper horizons indicate that present levels of contaminant input are less than they had been. It should be noted, however, that PCB concentrations throughout these cores were well below the surficial sediment concentrations at other stations within Segment 5. Core samples were composited over large intervals, possibly masking bands of high PCB contamination and precluding a conclusion about whether contamination is ongoing, historical, or both.

PCB distribution in surficial sediments of Hylebos Waterway Segments 2 and 3 is shown in Figure 7.2.9. The highest concentration of PCBs was 2,000 ug/kg (Segment 2, Station HY-22). This same station is identified elsewhere in this report as a site of anomalously high concentrations of chlorinated hydrocarbons, polycyclic aromatic hydrocarbons (PAH), and dibenzofuran. The high concentrations of these compounds and PCBs at this station may be a consequence of 1982 dredging by Pennwalt Corporation that exposed buried contaminated sediments. Less than 100 ug/kg PCB was found in surficial sediment samples (High 1982) just prior to the dredging.

Further evidence that the high PCB concentrations resulted from exposure of buried sediments is provided by a sediment core sample taken 150 m northwest of Station HY-22 prior to the 1982 dredging (Riley 1981, Station 3). PCB concentrations in this core (Figure 7.2.10, top) increased with depth down to at least 0.35 m in the sediment. The highest PCB concentration observed in these buried sediments (2,500 ug/kg) corresponded closely to that observed in the surficial sediments at Station HY-22 (2,000 ug/kg). This suggests that lower PCB-contaminated horizons noted in Riley's (1981) core are now exposed on the surface at Station HY-22 as a result of the recent dredging and that the contamination is principally historical.

A relatively high PCB concentration (1,500 ug/kg) was also apparent in the central portion of the waterway at Station HY-23, 12,000 ft from the mouth. The 1982 Pennwalt dredging was restricted to within 40 m of the shoreline and therefore would not have affected PCB concentrations at Station HY-23. The reason for the elevated PCB levels at HY-23 is unknown. Possible explanations include ship scour or release from adjacent dredging operations.

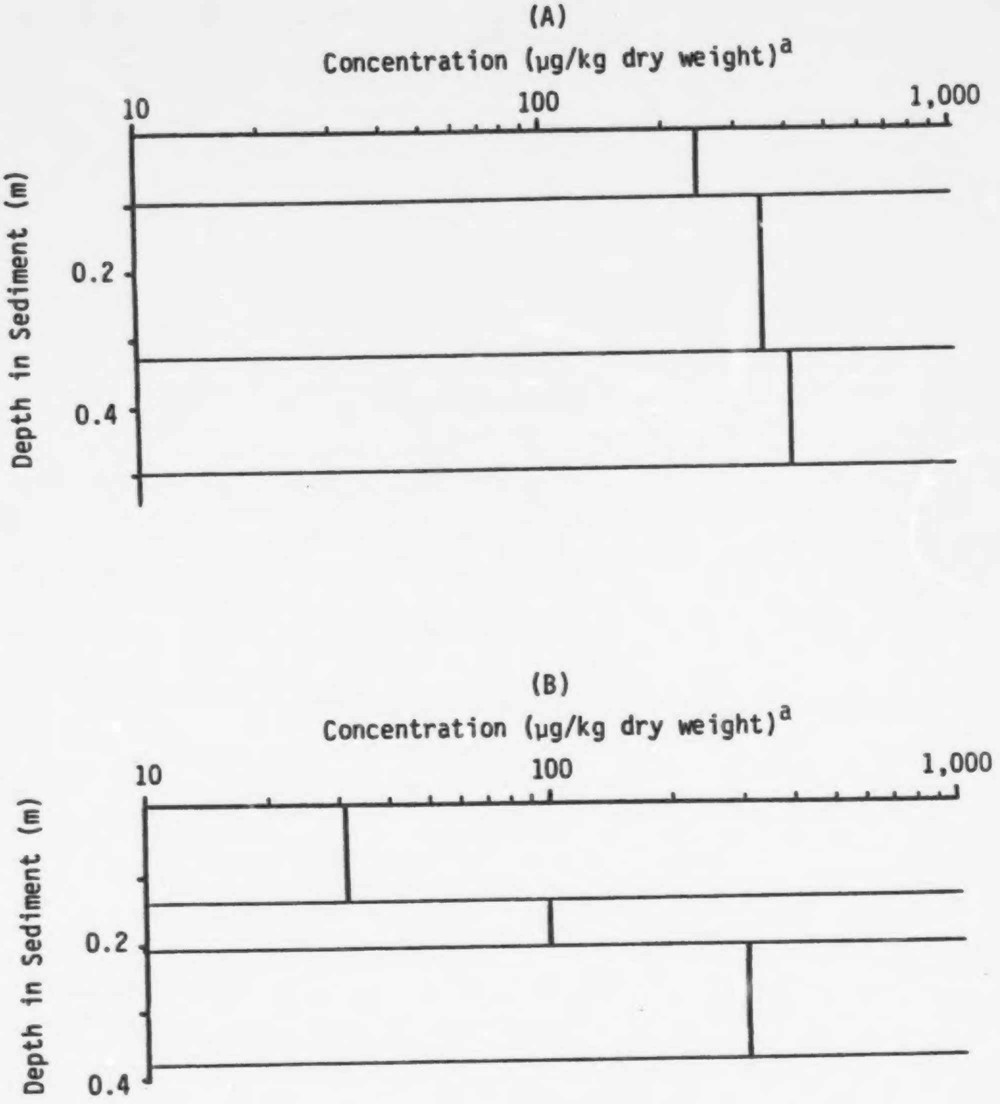


Figure 7.2.8

CONCENTRATIONS OF TOTAL PCBs WITH DEPTH IN THE SEDIMENT COLUMN
(Station locations are shown in Figure 7.2.4)
(A) STATION HY-63B,B03
(B) STATION HY-63C,B05

[a] No AET exceeded in these cores
(see Table 4.2 for AET values)

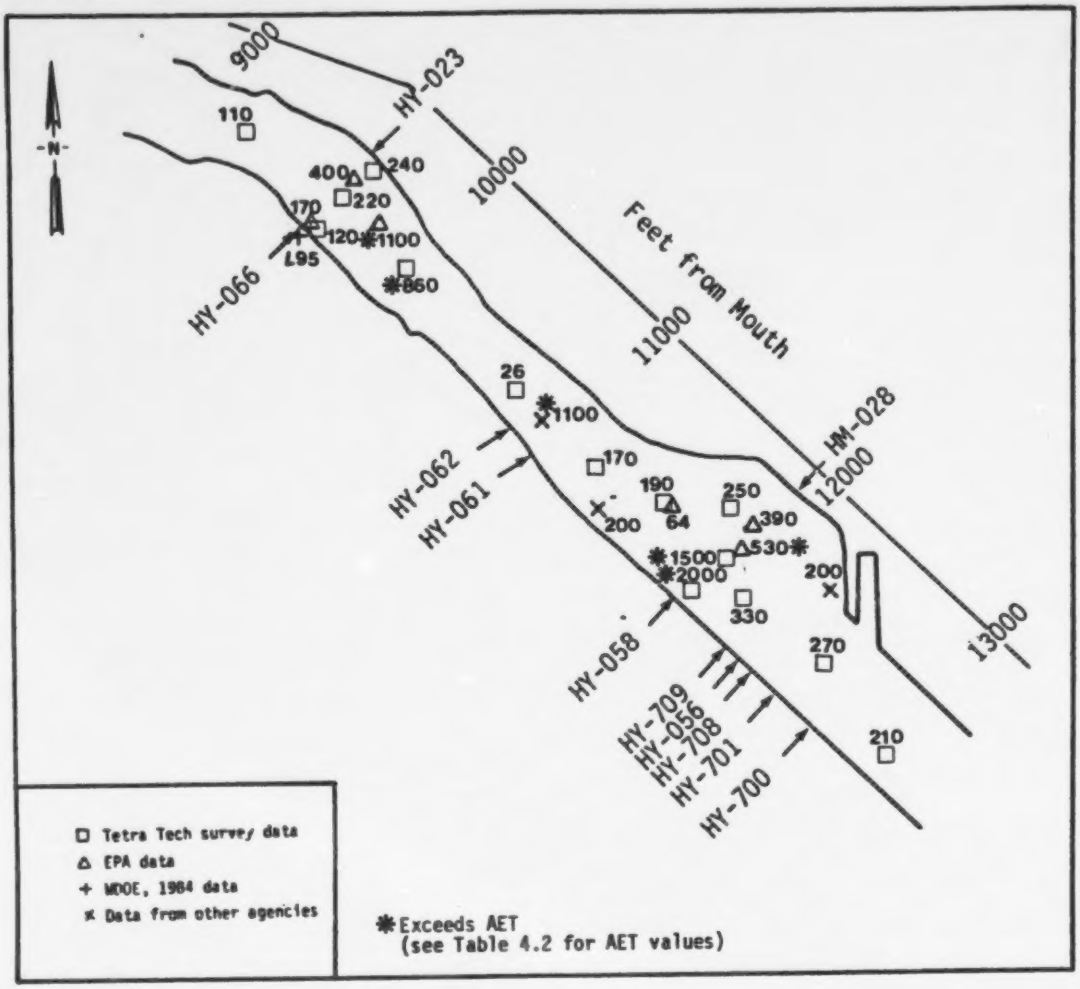


Figure 7.2.9

CONCENTRATIONS OF TOTAL PCBs IN THE SURFICIAL SEDIMENTS
OF HYLEBOS WATERWAY SEGMENTS 2 AND 3
(µg/kg dry weight)

L = At least one of the components of the group was undetected; sum includes the detection limit.

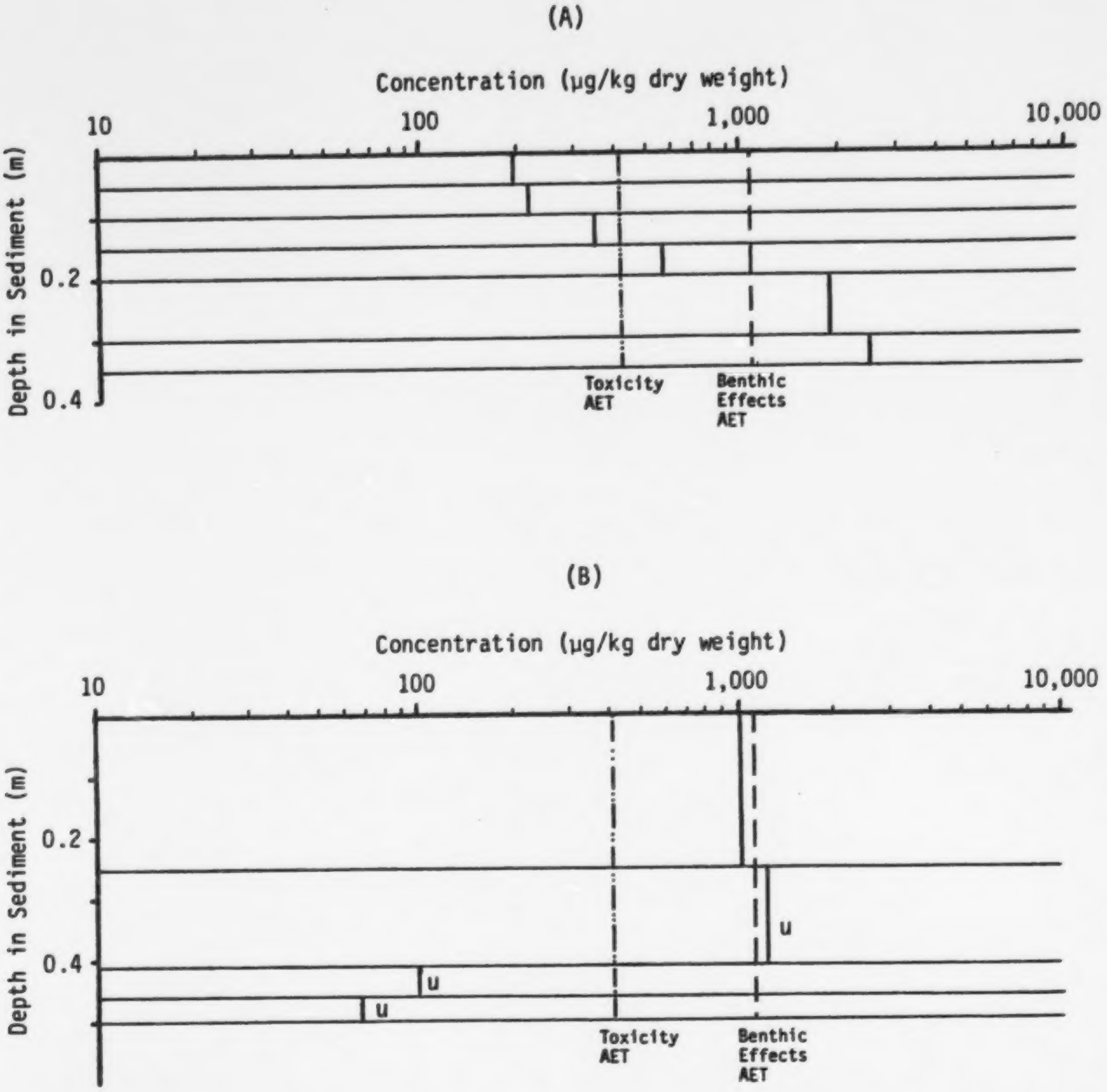


Figure 7.2.10

CONCENTRATIONS OF TOTAL PCBs WITH DEPTH IN THE SEDIMENT COLUMN
(A) RILEY (1981), STATION 3
(B) STATION HY-61, B02

u = undetected at concentration shown

PCB concentrations were also high (860-1,100 ug/kg) in sediments from Hylebos Waterway Segment 3 near the Lincoln Avenue drain (HY-066) and drains HY-062 and HY-061 (Figure 7.2.9). These drains do not appear to be potential recent sources, as shown by the low level of contamination in other stations near the drains. Therefore, the distribution of PCBs in this segment is patchy, as in other waterway areas, and the sources are undetermined.

7.2.3.2 Loading Estimates--

The only discharge to Hylebos Waterway documented to contain PCBs is Kaiser Ditch (HK-052). One effluent sample from this ditch contained less than 2 ug/L PCB (WDOE unpublished). No PCBs were found in nine other analyses of the discharge (detection limits 0.1-2 ug/kg for individual Aroclor mixtures). All other discharges to Hylebos Waterway in which PCBs have been undetected are listed in Table 7.2.1.

7.2.3.3 Source Identification--

Although there are several potential sources of PCBs, both historical and possibly ongoing, sediment data and the available loading data do not allow confirmation of either historical or ongoing sources.

7.2.3.4 Summary and Recommendations--

In both lower Hylebos Waterway (Segment 5) and upper Hylebos Waterway (Segments 2 and 3), the spatial patterns of PCB contamination were highly variable. This distribution suggests that there are no major contributions by ongoing sources. In lower Hylebos Waterway, PCB concentrations were elevated along the length of the Occidental Chemical Corporation waterfront. In upper Hylebos Waterway, sediment PCB concentrations were elevated in several areas, including a site adjacent to the Pennwalt Corporation's dock and main outfall. This elevation may have resulted from the recent exposure of buried sediments.

It is unknown in most areas whether high PCB levels in Hylebos Waterway sediments result from ongoing or historical sources. The highly variable PCB levels in surficial sediments may result from exposure of historically contaminated sediments (e.g., from ship scour or dredging) or from transport and deposition of contaminated sediments within the waterway. Several industrial activities (e.g., transformer installations) on Hylebos Waterway could be ongoing sources of PCBs. However, the composition of PCBs within waterway sediments is not characteristic of unweathered PCBs from transformers. PCB concentrations in Hylebos Waterway did not correlate with those of any other contaminant for which a potential source has been identified.

Commercial PCB mixtures are often significantly altered by physicochemical and biological processes after they are released into the terrestrial or marine environment. Sedimentary PCB assemblages commonly reflect alterations that have occurred during environmental transport as well as alterations that have occurred after deposition in the sediments. Among the most important environmental processes that modify PCB mixtures are oxidative microbial

Table 7.2.1

DISCHARGES TO THE HYLEBOS WATERWAY IN WHICH PCBs HAVE BEEN UNDETECTED

Drain #	Name	No. of Analyses	Detection Limit (ug/L for Individual Aroclor Mixtures)
HC-000	Hylebos Creek	4	0.1-2
HM-028	Morningside Ditch	5	0.1-2
HY-021	30" concrete pipe	1	0.1
HY-023	18" concrete pipe	1	0.1
HY-040	8" concrete pipe	1	1-2
HY-054	East Channel Ditch	2	0.1-2
HY-056	6" concrete pipe	1	0.1
HY-058	Main Pennwalt outfall	1	unspecified
HY-066	Lincoln Avenue Drain	3	0.1-2
HY-076	30" concrete pipe	1	0.1
HY-078	12" concrete pipe	3	0.5-2
HY-083	2 seeps at Occidental	2	0.5-2
HY-085	7 steel pipes	2	0.05-2
HY-700	Pennwalt East Seep	3	0.05-2
HY-707	Main Occidental outfall	5	1
HY-709	Pennwalt sewer pipe	1	0.1

degradation (which tends to preferentially affect less chlorinated PCB congeners), the loss of more water soluble (less chlorinated) congeners to an aqueous phase, and the loss of more volatile (less chlorinated) congeners to a vapor phase. As a net result of one or more of these processes, sedimentary PCB mixtures are often enriched in more highly chlorinated congeners relative to the commercial mixtures from which they derived. Therefore, the observation that PCB mixtures in Hylebos sediments appear to be weathered does not imply that the deposits are historical only. The weathering processes may occur on land (e.g., in a landfill) with subsequent transport to and ongoing contamination of the waterways.

A general survey of possible upland PCB sources should be conducted in areas adjacent to Hylebos Waterway, particularly in areas near potential sources (e.g., transformer installations). Additional data on the vertical distribution of PCBs in Hylebos Waterway sediments should be collected. Future dredging activities in Hylebos Waterway should minimize exposure of deeper sediments that may be contaminated by PCBs.

7.2.4 Aromatic Hydrocarbons

7.2.4.1 Spatial Distribution--

Both low and high molecular weight polycyclic aromatic hydrocarbons (LPAH and HPAH) have been identified as preliminary contaminants of concern in Hylebos Waterway within Segments 1, 2, and 4. Surficial sediment concentrations of LPAH ranged from 237 to 52,000 ug/kg with most sediments below 3,000 ug/kg (Figure 7.2.11). The highest concentrations occurred in three areas. The maximum value for LPAH was observed off the Kaiser Ditch in Segment 1. Concentrations dropped from 52,000 ug/kg at the ditch to 3,700 ug/kg dry weight at the nearest Tetra Tech sampling station (HY-16). A second peak was located near 12,000-14,000 ft from the waterway mouth (Hylebos Waterway Segment 2), along the south shoreline and in the central channel (Figure 7.2.12). As noted earlier, the sediments nearest the southern shoreline in this area (Station HY-22, 4,400 ug/kg LPAH) may have been disturbed by recent dredging.

The third peak was within a broad area between 3,000 and 7,000 ft from the waterway mouth (Segments 4 and 5). From a two-dimensional plane view (Figure 7.2.12), concentrations in this region were elevated relative to those in other areas, but there was no consistent spatial gradient of contamination within the area itself. LPAH concentrations were elevated in numerous isolated stations (e.g., 9,500 ug/kg at a 1984 WDOE station on the south shore by Drain HY-078, and 12,000 ug/kg near the Naval Reserve Dock), suggesting multiple sources rather than a dominant point source.

High LPAH concentrations were also found at a single staton (HY-16) at 14,000 ft from the mouth of the waterway, immediately off the Kaiser Ditch outfall. At two stations from historical studies, anomalously high concentrations for LPAH were found. These stations (the Naval Reserve dock, at 5,000 ft from the mouth, and drain HY-078, at 6,900 ft from the mouth) are discussed in Section 7.2.4.3 (Source Identification).

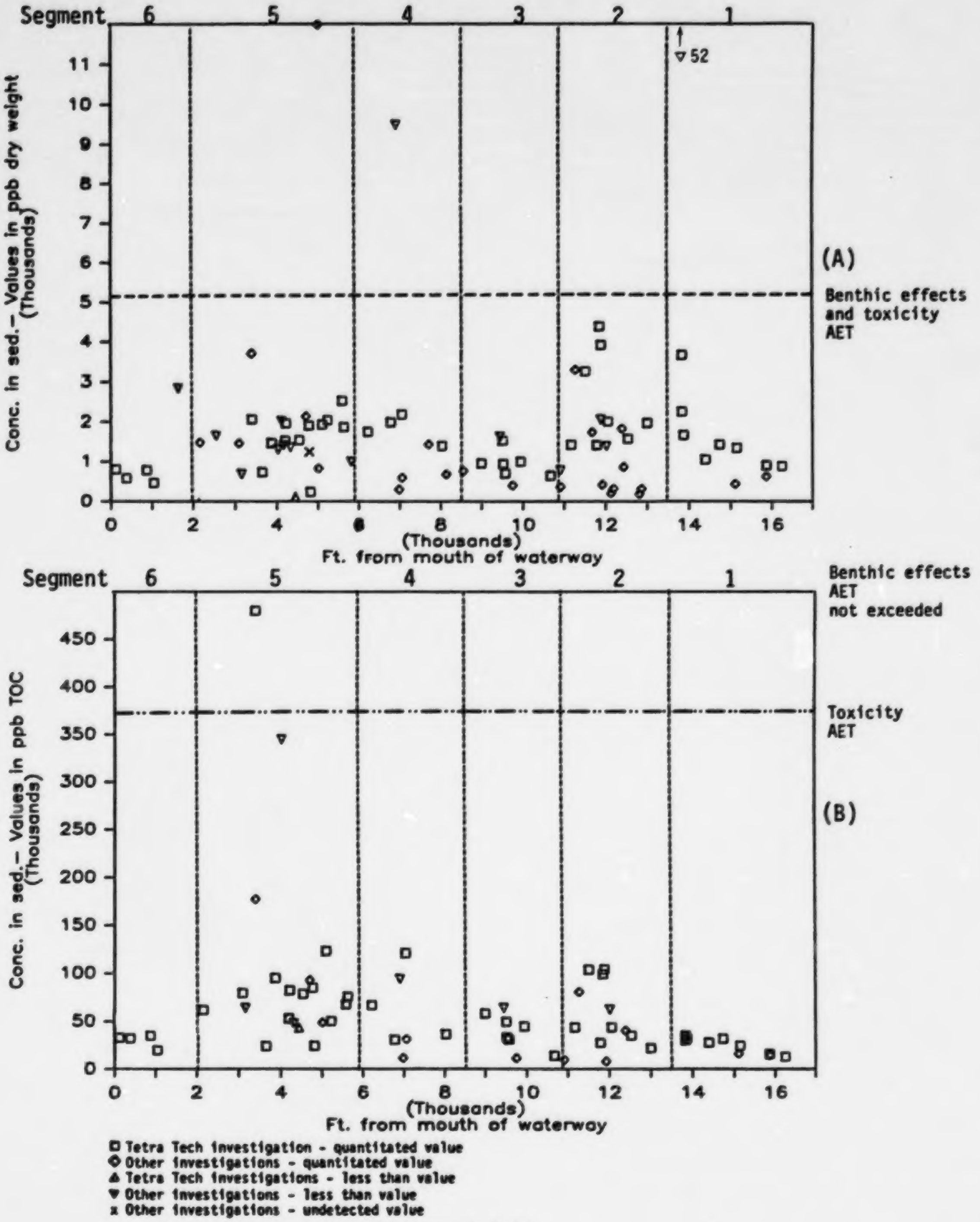


Figure 7.2.11

CONCENTRATIONS OF TOTAL LOW MOLECULAR WEIGHT POLYCYCLIC AROMATIC HYDROCARBONS IN THE SURFICIAL SEDIMENTS OF THE HYLEBOS WATERWAY WITH DISTANCE FROM THE MOUTH OF THE WATERWAY
(A) Concentrations on a dry weight basis
(B) Concentrations normalized to total organic carbon content of the sediments

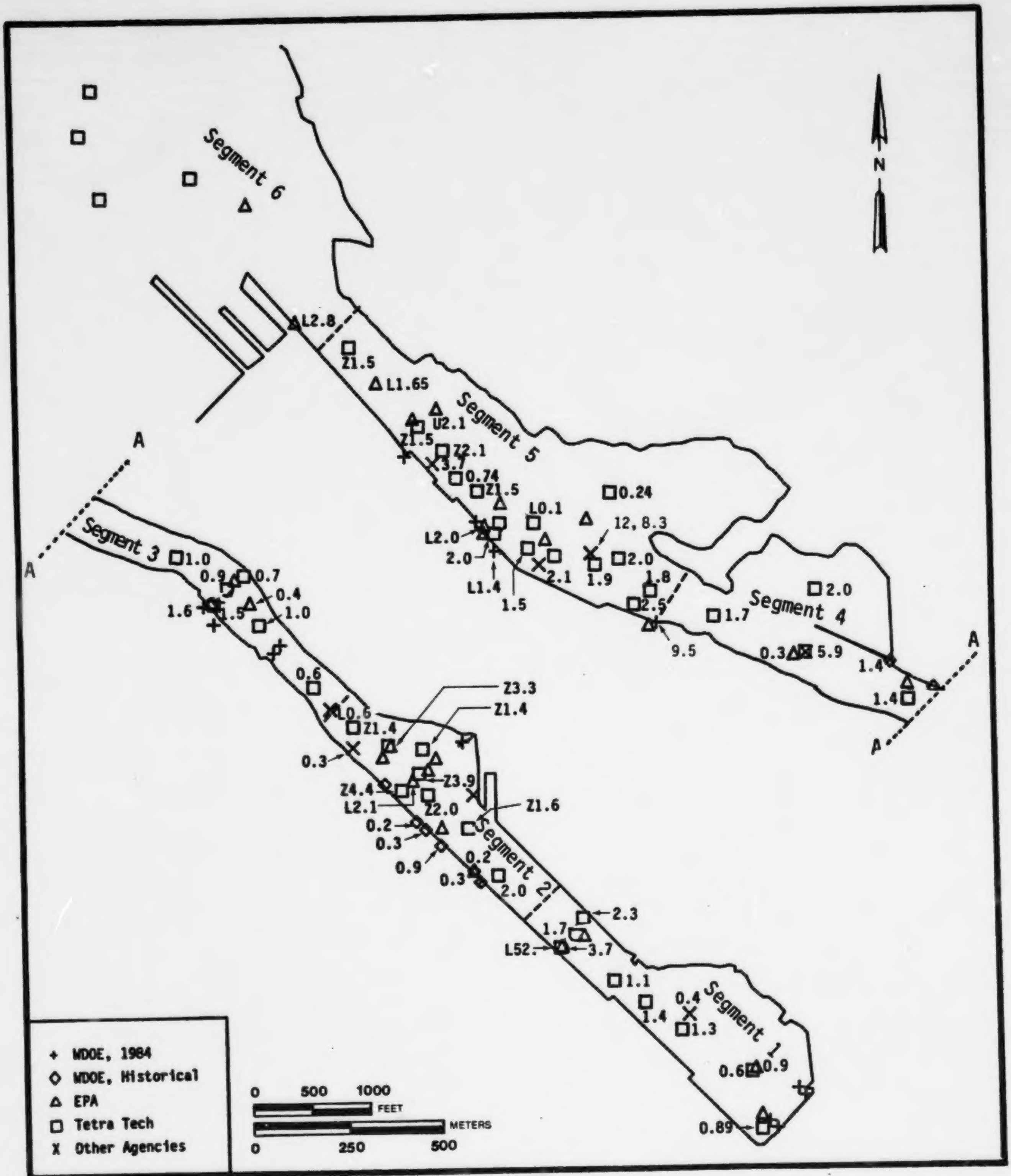


Figure 7.2.12

SURFICIAL SEDIMENT CONCENTRATIONS OF LPAH IN HYLEBOS WATERWAY

L = At least one of the components of the group was undetected, sum included the detection limit.
Z = Data corrected for blank.
U = Indicates undetected at value shown.

Patterns of HPAH concentrations in surficial sediments of Hylebos Waterway (Figures 7.2.13, 7.2.14) were quite different from those of LPAH. Concentrations of HPAH peaked dramatically at 14,000 ft from the mouth of the waterway (Segment 1), decreasing towards both the head and mouth of the waterway. When normalized to the total organic carbon content of the sediments, there was only a slight decrease in the average HPAH concentration in sediments near the mouth of the waterway compared to those near the head (Figure 7.2.13). Therefore, the substantial HPAH concentrations observed on a dry-weight basis appear to be associated with an accumulation of HPAH- contaminated organic material in the sediment. It is likely that a major organic carbon source in the vicinity of 14,000 ft from the mouth of Hylebos Waterway is also the major HPAH source. Maximum HPAH concentrations occur on the south shore at the Kaiser Ditch (370,000 ug/kg dry weight, Figure 7.2.14).

The two- and three-ring PAH that constitute the LPAH group are most abundant in uncombusted fossil fuels such as petroleum, oil shales, and their refined products. The four- to six-ring PAH that constitute HPAH group are generated by combustion of wood and fossil fuels (Lee et al. 1977). Thus, a comparison of the relative abundances of LPAH and HPAH in the environment may sometimes indicate whether the predominant source is the combusted fuels or uncombusted fossil hydrocarbons. The HPAH-to-LPAH ratio for sediments of Hylebos Waterway increased from the mouth of the waterway (ratio of approximately 2) to the head (ratio of approximately 11; Figure 7.2.15). This provides strong evidence that the sources of PAH to upper Hylebos Waterway are very different from those to lower Hylebos Waterway. The PAH in upper Hylebos Waterway are derived primarily from combustion. Those in lower Hylebos Waterway are derived relatively more from unburned fossil fuels.

The vertical pattern of PAH contamination in sediments was consistent throughout Hylebos Waterway (Figure 7.2.16). Generally, sediment core samples from the mouth of the waterway (HY-63), midway along its length (HY-61) and at the head (HY-60A) had greater concentrations of LPAH and HPAH in subsurface horizons relative to the less contaminated upper horizons (with the exception of HPAH in HY-63). This pattern has been observed in other sediments within central Puget Sound (Crecilius and Bloom in review; Barrick and Prahl in review). Concentrations of the LPAH in each of the cores exceeded benthic and toxicity AET at depth. HPAH concentrations at depth were well above AET toward the head of the waterway.

7.2.4.2 Loading Estimates--

Despite sampling of numerous discharges to Hylebos Waterway, few samples have been found to contain PAH, given the techniques and detection limits used (typically <10 ug/L). Kaiser Ditch (HK-052) is the only discharge that has consistently been found to contain PAH, and for which loading estimates are available. Based on 11 observations from June, 1980 to April, 1984, estimated loading is less than 0.046 lb/day LPAH, based on an average concentration of less than 3.2 ug/L (WDOE unpublished). Phenanthrene was

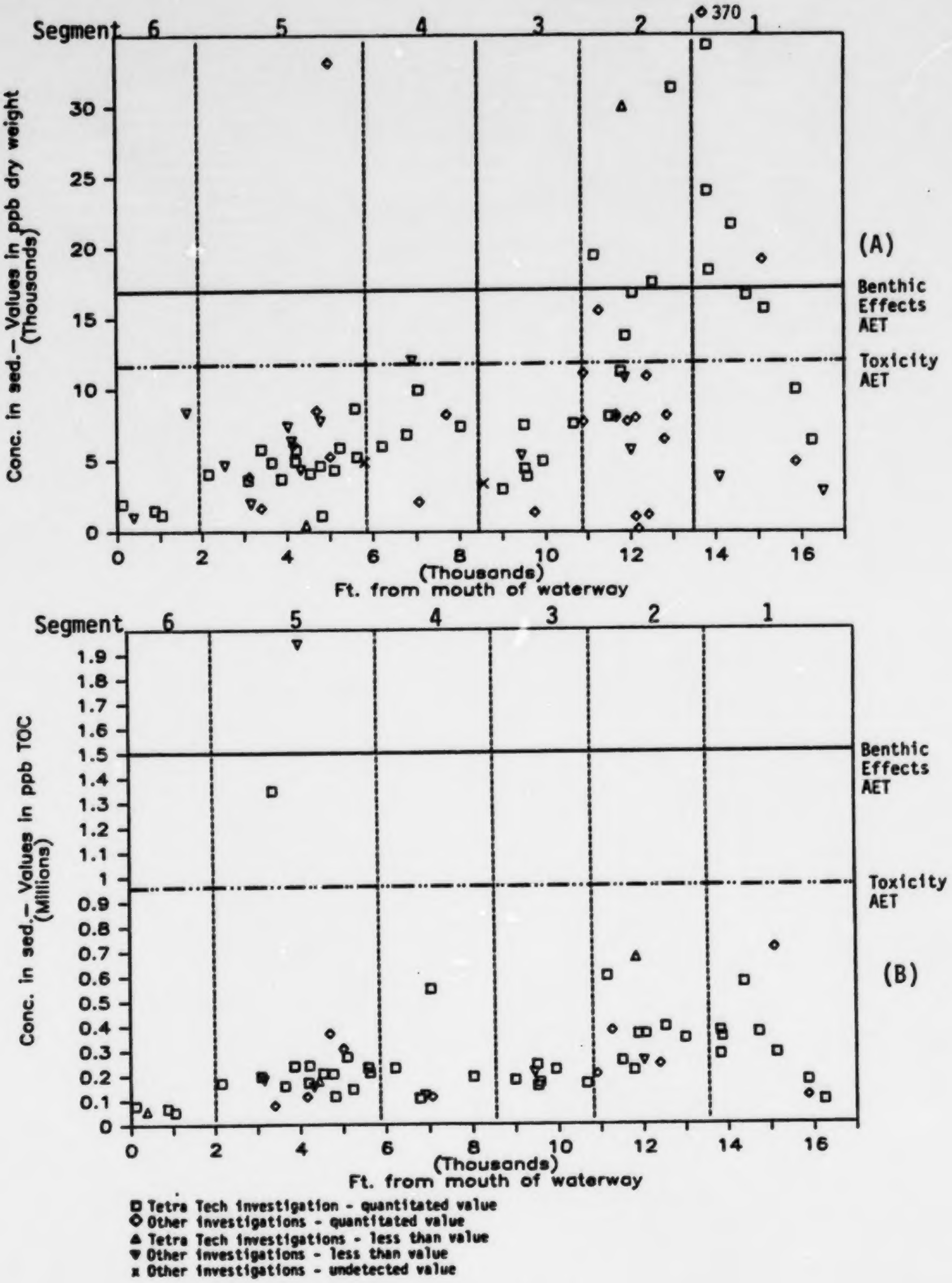


Figure 7.2.13

CONCENTRATIONS OF TOTAL HIGH MOLECULAR WEIGHT POLYCYCLIC AROMATIC HYDROCARBONS
IN THE SURFICIAL SEDIMENTS OF THE HYLEBOS WATERWAY WITH
DISTANCE FROM THE MOUTH OF THE WATERWAY
(A) Concentrations on a dry weight basis
(B) Concentrations normalized to total organic
carbon content of the sediments

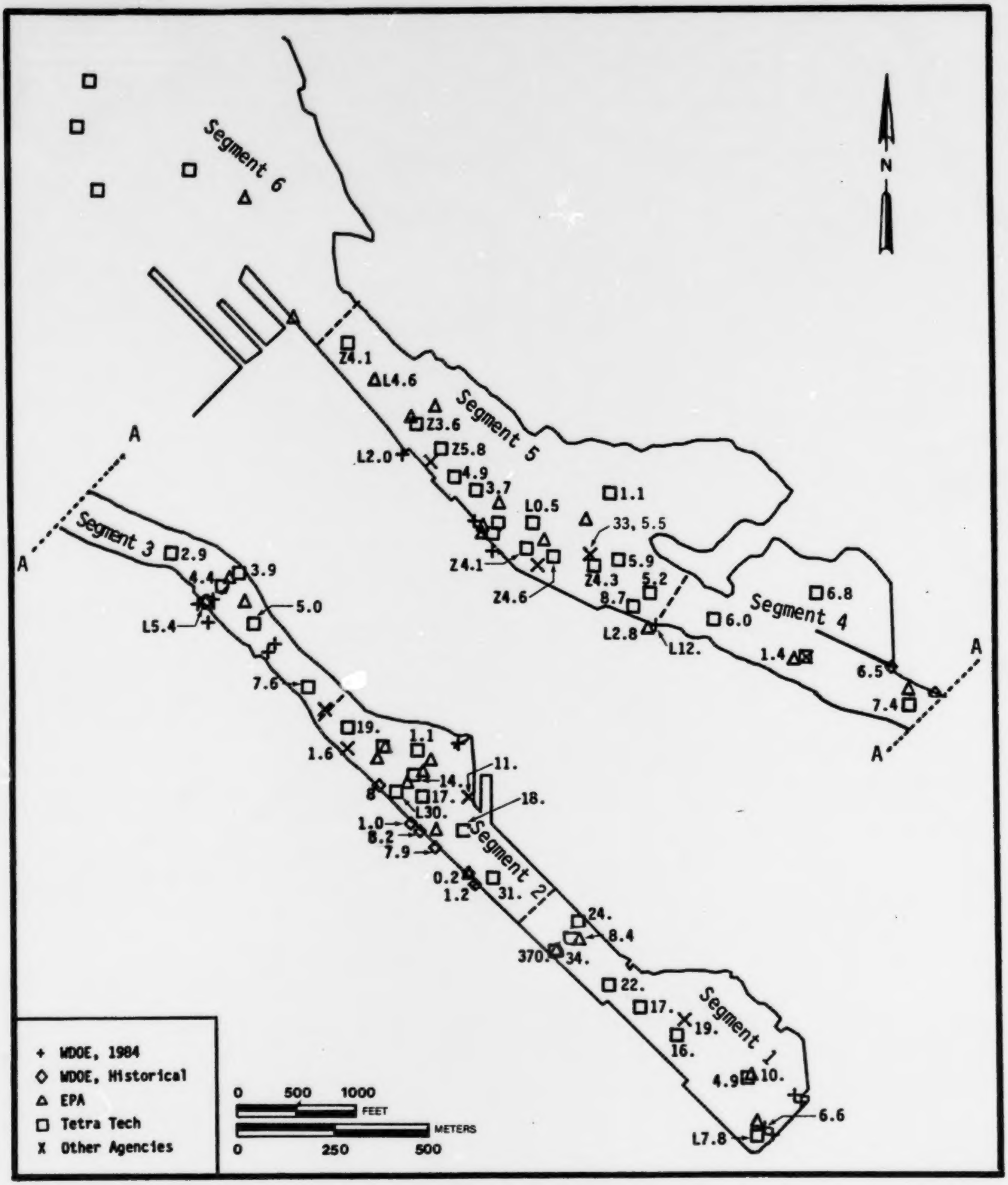


Figure 7.2.14

SURFICIAL SEDIMENT CONCENTRATIONS OF HPAH IN HYLEBOS WATERWAY

L = At least one of the components of the group was undetected,
sum included the detection limit.
Z = Data collected for blank.

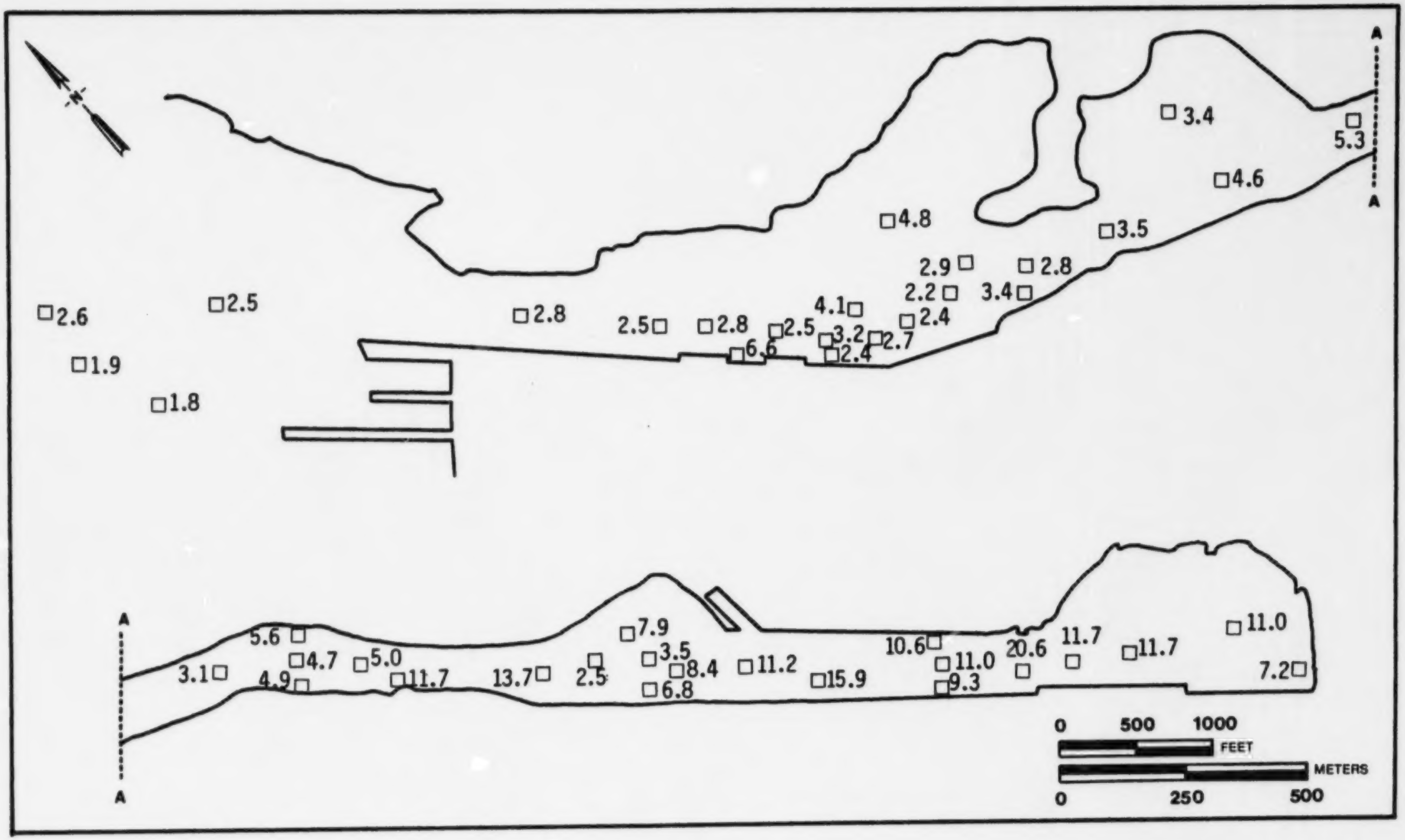


Figure 7.2.15

RATIO OF THE CONCENTRATIONS OF TOTAL HIGH MOLECULAR WEIGHT PAH
TO TOTAL LOW MOLECULAR WEIGHT PAH AT ALL TETRA TECH
SURVEY STATIONS IN THE HYLEBOS WATERWAY

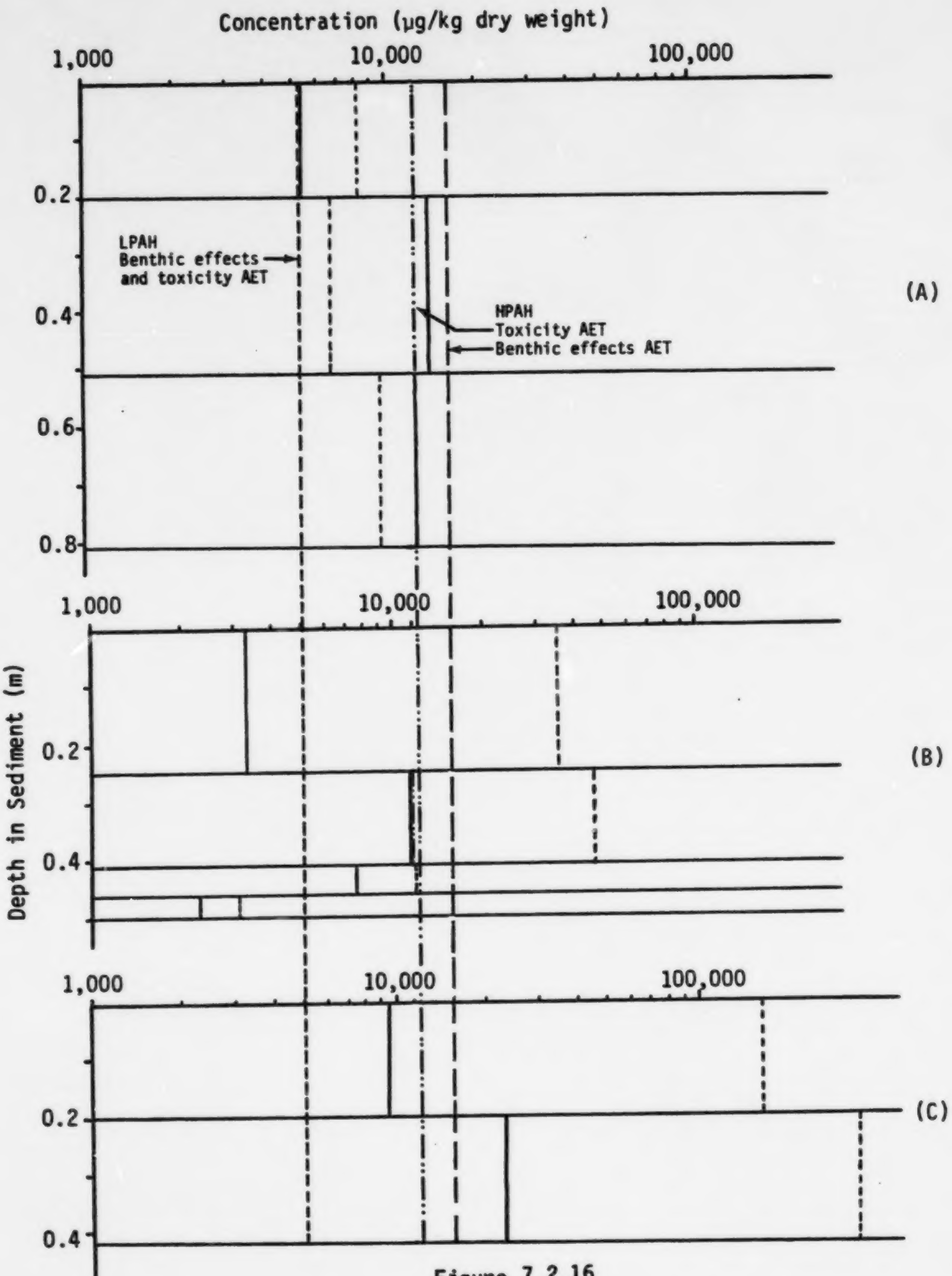


Figure 7.2.16

CONCENTRATIONS OF PAH WITH DEPTH IN THE SEDIMENT COLUMN
(A) STATION HY-63, G01; (B) STATION HY-61, B02;
(C) STATION HY-60A, B01

—— Low molecular weight PAH
----- High Molecular weight PAH

the LPAH detected most consistently in the samples. Estimated loading of HPAH during the same period is less than 0.15 lb/day, based on an average concentration of less than 10.4 ug/L. The HPAH compounds consistently detected include pyrene, fluoranthene, chrysene, and benzofluoranthenes.

The PAH loading from deposition of stack emissions from Kaiser Aluminum have not been quanitifed. However, most of the PAH deposited within the study are probably enter Commencement Bay via surface water runoff because of the more extensive surface area for atmospheric fallout on land compared with direct deposition in the waterways.

PAH have also been detected in Morningside Ditch (HM-028), the East Channel Ditch (HY-054), a seep at U.S. Gypsum (HY-061), a drain near Buffelen Woodworking (HY-070), drains near Occidental Chemical Corporation (HY-085), and storm sewer and groundwater seeps along the Pennwalt Corporation shoreline (HY-056, HY-700, HY-701). However, because of low concentrations, infrequency of detection, and low estimated loadings, these discharges are not considered to be major sources of PAH to the waterway. Discharges that did not contain PAH are listed in Table 7.2.2. Insufficient data are available to make a reliable determination of the mass flux of PAH in Hylebos Waterway.

7.2.4.3 Source Identification--

The spatial gradients of contamination in Hylebos Waterway indicate two areas of elevated LPAH concentrations: 12,000 ft from the mouth (Segment 2) and 3,000 to 7,000 ft from the mouth (Segments 4 and 5). In addition, a source of HPAH was noted 14,000 ft from the waterway mouth (Segment 1). These three areas are discussed individually below.

Hylebos Waterway Segment 2-- The highest level of LPAH contamination (on a dry-weight basis) found in Hylebos Waterway during the Tetra Tech survey was observed at 12,000 ft from the waterway mouth, immediately adjacent to the Pennwalt dock and discharge point of the plant effluent. No LPAH have been found in the Pennwalt effluent above trace amounts (Yake 1982a, detection limits unspecified). However, one or more petroleum spills may have occurred at the dock. Fuel oil for plant consumption is received at the dock and piped to three storage tanks with a total 27,000-barrel capacity (U.S. Army COE 1983). A thorough search of WDOE files on Pennwalt Corporation and a review of recent WDOE Environmental Complaint files (1979-1985) uncovered only a single spill of petroleum on the Pennwalt property. On February 9, 1982, 200-300 gal of Bunker C oil were spilled, although less than 1 gal was estimated to have reached the waterway. Spills of sufficient volume to account for observed contamination of waterway sediments cannot be documented.

The relative proportion of alkylated LPAH was investigated to help determine the origin of the PAH in the sediments. PAH mixtures in uncombusted fossil fuels typically contain relatively more alkylated PAH than do combustion-derived PAH, which primarily contain only the nonalkylated analogs (Youngblood and Blumer 1975). Thus the ratio of 2-methyl phenanthrene to phenanthrene from a source of combustion-derived PAH can be expected to be relatively

Table 7.2.2

DISCHARGES TO THE HYLEBOS WATERWAY IN WHICH PAH HAVE BEEN UNDETECTED

Drain #	Name	No. of Analyses	Detection Limit (ug/L for Individual Aroclor Mixtures)
HC-000	Hylebos Creek	5	0.1-10
HY-016	Crack in Bulkhead	1	0.5
HY-017	12" corrugated pipe	1	unspecified
HY-018	8" steel pipe	1	0.5-50
HY-021	30" concrete pipe	1	10
HY-023	18" concrete pipe	1	10
HY-040	8" concrete pipe	1	0.1-1
HY-058	Pennwalt main outfall	2	unspecified
HY-062	12" concrete pipe	1	0.5
HY-066	36" concrete pipe	3	0.1-10
HY-070	Flow over bulkhead	1	0.5
HY-071	6" and 12" iron pipes	1	unspecified
HY-073	Open channel	1	0.5
HY-076	30" concrete pipe	1	10
HY-078	12" concrete pipe	2	0.1-1
HY-083	2 seeps at Occidental	2	0.1-1
HY-704	Sound Refining main outfall	2	unspecified
HY-707	Occidental main outfall	5	10
HY-709	Pennwalt sewer pipe	2	1

low. Uncombusted PAH, as would be involved in a spill, can be expected to have a higher 2-methyl phenanthrene-to-phenanthrene ratio. This ratio was calculated for all Tetra Tech stations in Hylebos Waterway and showed extreme variation (0.056-0.63) with no apparent gradient. The sample immediately adjacent to the Pennwalt dock (Station HY-22) had the highest ratio (0.63) of all stations, but there were no samples where methylated phenanthrenes were found in higher concentration than phenanthrene as is often found in fuel oils. If spills have occurred, there has probably been considerable degradation of the oils.

As noted earlier, Pennwalt Corporation dredged an area immediately adjacent to the plant dock in 1982. Station HY-22 was within this area and, therefore, the sample probably represented deeper sediments exposed by recent dredging. The sediment cores indicate that PAH concentrations in subsurface sediments were typically greater than those of surface sediments. Therefore, the high PAH concentrations at Station HY-22 are probably not a consequence of proximity to a source, but instead, result from sampling buried, contaminated sediments exposed by the recent dredging.

Elevated LPAH concentrations (3,300-3,900 ug/kg) noted in the central waterway off the Pennwalt Corporation cannot be explained. No source has been identified for the contamination in the central waterway.

Hylebos Waterway Segments 4 and 5--Sediments from a broad area of lower Hylebos Waterway (3,000 to 7,000 ft from the mouth) had elevated concentrations of LPAH. Within this area, there were two stations with extremely high LPAH concentrations (at 5,000 ft and 6,900 ft from the mouth). The station at 5,000 ft is off of the Naval Reserve dock, a facility known to have discharged petroleum products. Concentrations at other stations in this area were much lower, indicating that the area of elevation is relatively small. The station at 6,900 ft is off of drain HY-078. Concentrations at other stations in this area also were much lower, indicating that the area of elevation is relatively small. Samples from drain HY-078 and neighboring drain HY-076 have been analyzed for LPAH (HY-078 twice and HY-076 once) and none were detected. Periodic releases from these drains are possible. These generally lower elevations are considered to indicate multiple sources rather than a dominant point source.

In the absence of a clear spatial gradient or documented discharge of PAH, it is impossible to definitively identify the ultimate sources. Such a conclusion is not surprising for a heavily industrialized waterway such as Hylebos Waterway. Because of ubiquity of fossil fuels and their combustion products, virtually every ship traveling the waterway and every industry along its banks is a potential source of PAH.

Any one of the industries surrounding Hylebos Waterway Segments 4 and 5 could be a potential source of LPAH (Table 7.2.3). None can be shown to be responsible for the observed contamination of Hylebos Waterway sediments. However, Sound Refining, PRI Northwest, and Cenex may be potential sources because oil and gasoline spills have been documented at these facilities. Source identification efforts are hindered by (1) apparent absence of spatial

Table 7.2.3

POTENTIAL INDUSTRIAL SOURCES OF POLYCYCLIC AROMATIC HYDROCARBONS IN HYLEBOS SEGMENTS 4 AND 5

Facility Name	Association with PAH	Known Problems
Sound Refining	Petroleum refinery; loading/unloading of petroleum products at wharf; fuel storage and distribution	Past leakage of oil/water mixture from lines leading to oil/water separator[a]
PRI Northwest (property formerly owned by Fletcher Oil)	Petroleum distributor; receipt of products by ship for overland distribution	69-gallon unleaded gas spill, 7/1/79[b]; 50-gallon gasoline spill, 3/17/80[b]; Floor of tank farm and surrounding berms built from dredge spoil; groundwater contamination possible[c]
Cenex (formerly Western Farmers)	Fuel tanks for trucks and equipment	200 to 300-gallon gasoline spill, 1/11/79, estimated 30 gallons reached the waterway[b]
Occidental Chemical Corporation	Receipt of fuel oil by ship for plant consumption	None
Tacoma Public Utilities, Steam Plant No. 2	Inactive steam plant; dock formerly used for receipt of fuel oil for plant consumption	None

---

[a] R. Robinson, Tacoma Sewer Utilities, pers. comm.

[b] WDOE Environmental Complaint Files

[c] J. Oberlander, WDOE, pers. comm.

gradients of contamination, (2) absence of documented discharges of appreciable quantities of PAH, and (3) numerous potential contaminant sources.

Hylebos Segment 1--The high HPAH concentrations noted in sediments of upper Hylebos Waterway at about 14,000 ft from the mouth of the waterway corresponded to the location of the Kaiser Ditch discharge. A single sample with high LPAH concentrations (3,680 ug/kg) was collected near the same outfall. Discharge from the ditch has consistently had detectable quantities of LPAH and HPAH. The following discussion is focused on HPAH, since the spatial gradients of contamination and loading information indicate that the ditch is a much greater source of HPAH than of LPAH.

There are two principal sources of HPAH to Kaiser Ditch: atmospheric emissions and wet scrubber sludges from Kaiser Aluminum and Chemical Corporation. Atmospheric emissions from Kaiser Aluminum and Chemical Corporation may enter Kaiser Ditch via direct deposition or via runoff from areas where particulate emissions have been deposited on the ground. Though very little data are available to quantify HPAH loading from this source, the limited data that do exist suggest that release of HPAH from atmospheric emissions at Kaiser are and have been significant. Each Soderberg cell at Kaiser has a hood that is vented to a baghouse. Potroom roof monitors, which receive only contaminants that escape the hoods, were releasing 0.67 lb/day benzo(a)pyrene in 1984 (Fenske 1985). The benzo(a)pyrene loading from total atmospheric emissions at Kaiser may be much greater. There has been no known attempt to quantify HPAH loading from the baghouses. Particulate material settling on Kaiser's potroom roofs contains 1.1 percent PAH (Nord 1983), thus providing additional evidence that atmospheric emissions from Kaiser Aluminum and Chemical Corporation may represent a significant source of PAH.

It is not possible to quantify the PAH loading from atmospheric emissions, either by direct deposition in the waterway or via runoff. However, given the relative land and water surface areas, it is reasonable to assume that most of the HPAH entering Hylebos Waterway that originated from atmospheric sources at Kaiser would first be deposited on land, then enter Kaiser Ditch or other surface water drains, and eventually discharge into Hylebos Waterway via runoff.

Wet scrubber sludges represent a second source of HPAH to Kaiser Ditch. In an effort to reduce atmospheric emissions from the aluminum smelting process, Kaiser Aluminum and Chemical Corporation operated a wet scrubbing system from 1964 to 1974. The wet scrubbing generated a sludge containing aluminum, reduction cell bath materials, carbon, and condensed pitch volatiles (Hanneman 1984). This sludge was discharged initially to a settling pond and was later moved to two nearby diked disposal areas in the western portion of the plant property (Landau 1984). Generation of sludge ceased in 1974 when the wet scrubber system was replaced with a dry scrubber that recirculates particulate material. In 1983 it was discovered that the wet scrubber sludges on the plant property contained up to five percent PAH and could be classified by Washington State regulations as an "extremely hazardous waste" on the basis of both bioassay and PAH analyses (Stanley 1983; Landau 1984).

Sampling of Kaiser Ditch, which is adjacent to the sludge disposal areas and ultimately discharges to Hylebos Waterway, indicated that ditch sediments were contaminated with up to 300,000 ug/kg PAH (Landau 1984). A recent survey of Hylebos Waterway sediments near the outfall of Kaiser Ditch found high concentrations of PAH attributable to Kaiser but concluded (Landau 1984)

- Release of PAH from Kaiser Aluminum and Chemical Corporation occurred principally during dredging of the wet scrubber settling ponds in 1969 and 1971.
- PAH-contaminated sediments (concentrations >500 ug/kg dry weight) attributable to the firm are buried beneath relatively uncontaminated sediments of recent deposition.
- There is no evidence of contemporary deposition of PAH from Kaiser Aluminum and Chemical Corporation, based on the absence of PAH in the upper sediments at concentrations above "background" levels and the absence of the Kaiser sludge chemical "fingerprint" in surficial sediments.

The present investigation provided much additional data with which to reassess Landau's (1984) conclusions:

- The "background" concentrations referred to by Landau (1984) are still much higher than Puget Sound reference areas. PAH concentrations in the surface sediments near the ditch exceeded AET determined in this study.
- As shown by the sediment core data, contamination by HPAH was considerably worse historically than at present.
- As shown by the spatial pattern of contamination, Kaiser Ditch appears to be the source of the HPAH in surficial sediments of upper Hylebos Waterway.
- As indicated by loading estimates, the ditch was a source of LPAH and HPAH in 1983-1984, although concentrations may have been considerably less than they had been historically (e.g., during hydraulic dredging of the sludge settling pond).

7.2.4.4 Summary and Recommendations--

Three areas of Hylebos Waterway were found to contain elevated concentrations of PAH. In lower Hylebos Waterway (Segments 4 and 5), no source could be definitively identified because of the absence of clear spatial gradients of sediment contamination, the lack of documented discharges of appreciable quantities of PAH, and the number of potential sources. Contamination is believed to be a consequence of multiple sources. Small areas of relatively high LPAH concentrations were observed near the Naval Reserve dock and a drain (HY-078) near the 11th Street bridge.

In Segment 2, elevated PAH concentrations in sediments off the Pennwalt Corporation dock (Station HY-22) probably reflect historical contamination exposed by recent dredging. No source could be identified for the LPAH contamination in the central waterway.

The largest single source of HPAH to Hylebos Waterway appears to be Kaiser Aluminum and Chemical Corporation via discharge through Kaiser Ditch. The firm's contribution to contamination of Hylebos Waterway sediments is based on:

- High concentrations of HPAH in sediments immediately off Kaiser Ditch, in comparison to relatively low concentrations elsewhere in Hylebos Waterway
- Similarity of HPAH composition between selected Hylebos Waterway sediments and Kaiser Aluminum and Chemical Corporation sludge samples
- On-site disposal of sludges containing up to 5 percent PAH
- Known discharges from the sludge pits into Kaiser Ditch as a result of surface water runoff, hydraulic dredging, and the historical discharge of plant wastewater into the sludge ponds
- Contamination of Kaiser Ditch sediments with up to 300,000 ug/kg PAH
- Consistent detection of PAH in discharge from Kaiser Ditch
- Documentation of atmospheric release and deposition of PAH at Kaiser Aluminum and Chemical Corporation.

Based on the elevated concentrations of HPAH in subsurface sediments, historical levels of contaminant input were considerably greater than they are currently. Kaiser Ditch appears to be a continuing source of contamination, based on:

- Detection of PAH in Kaiser Ditch effluent as recently as April, 1984
- Elevation of HPAH concentrations in surficial sediments immediately off Kaiser Ditch

- Concentrations of PAH in suspended sediments at the head of the waterway that exceeded those in all other suspended sediment samples from Commencement Bay.

The proportion of HPAH in the Kaiser Ditch effluent originating from the wet scrubber sludges, runoff containing particulate matter from atmospheric emissions, and residual HPAH in ditch sediments cannot be determined. The relative contribution of these sources will have to be determined in order to best direct remedial actions.

Kaiser Aluminum and Chemical Corporation and the WDOE are aware of the potential contamination problems posed by the wet scrubber sludge and have taken steps to minimize the potential for environmental release. The following actions have been taken (Fenske, F., personal communication; Burkhalter, R., personal communication):

- Plant wastewater no longer flows through the sludge-contaminated ponds prior to discharge to Hylebos Waterway.
- A tide gate has been reinstalled at the mouth of Kaiser Ditch.
- Surface water runoff from the sludge ponds percolates into the ground or is diverted through a dike with a filter fabric prior to discharge to Kaiser Ditch.
- The WDOE is currently reviewing a Kaiser Aluminum and Chemical Corporation proposal to move sludges now contained in three separate diked enclosures into a single enclosure, cover this area with an impermeable cap, and initiate a groundwater monitoring program for PAH.

Recent and proposed remedial actions should reduce the contribution of the sludge ponds to the HPAH in Kaiser Ditch effluent. Because the relative contribution of atmospheric particulate emissions deposited on plant property and reaching Kaiser Ditch via surface water runoff has not been established, Kaiser Ditch HPAH loading after stabilization of the sludge ponds cannot be predicted. The rate at which sediment HPAH concentrations in Hylebos Waterway will reflect a decrease in HPAH input cannot be predicted without additional data on sediment transport and deposition in the waterway.

The following recommendations may help define other sources of PAH to Hylebos Waterway:

- Investigate the Naval Reserve facility, drains HY-078 and HY-076, Sound Refining, PRI Northwest, and Cenex as sources of LPAH.
- Evaluate HPAH in storm water near the Kaiser facility.

- Continue efforts to stabilize or remove the wet scrubber sludges. When completed, monitor surface water runoff from the area to ensure that HPAH do not continue to migrate to Kaiser Ditch.

- If HPAH input from atmospheric emissions and the sludge ponds can be curtailed or eliminated, or is found to be insignificant, remove contaminated sediments within Kaiser Ditch. These sediments contain up to 300,000 ug/kg PAH and therefore will represent a continuing source of PAH to Hylebos Waterway.

7.2.5 Dibenzofuran

7.2.5.1 Spatial Distribution--

The spatial distribution of dibenzofuran in surficial sediments of Hylebos Waterway is shown in Figure 7.2.17. Dibenzofuran concentrations in sediments from a broad area between 3,000 and 7,000 ft from the waterway mouth (Segments 4 and 5) appeared slightly higher than those elsewhere in the waterway. Sediments from a single station 12,000 ft from the mouth (HY-22 in Segment 2) were higher than those from surrounding stations.

There was strong similarity between the spatial distribution of dibenzofuran in Hylebos Waterway sediments and that of LPAH (Figure 7.2.11). The correlation between dibenzofuran and LPAH concentrations is discussed in Section 3.1.5.2. Concentrations of dibenzofuran normalized to organic carbon were fairly uniform except at Station HY-44 (35 mg/kg TOC). This station contained 94 percent sand and little organic carbon. The observed high loading of contaminants when normalized to the small amount of fine-grained material probably reflects proximity to the source for this coarse-grained sediment.

Sediment core data indicate that input of dibenzofuran to Hylebos Waterway was greater historically than at present. Contamination in subsurface horizons was up to about 20 times greater than in the upper horizon.

7.2.5.2 Loading Estimates--

The only discharge to Hylebos Waterway that has been found to contain dibenzofuran is Kaiser Ditch (HK-052). Concentrations of approximately 0.7 ug/L dibenzofuran were measured in recent samples collected by the WDOE (unpublished). The following discharges have been analyzed for dibenzofuran, although none were detected at 0.1 ug/L: HY-054, HY-066, HY-078, HY-083, HY-085, and HY-700.

7.2.5.3 Source Identification--

Although dibenzofuran is used as an insecticide (Hawley 1981), this potential source is not considered significant in Hylebos Waterway because the areas of major dibenzofuran contamination were not associated with

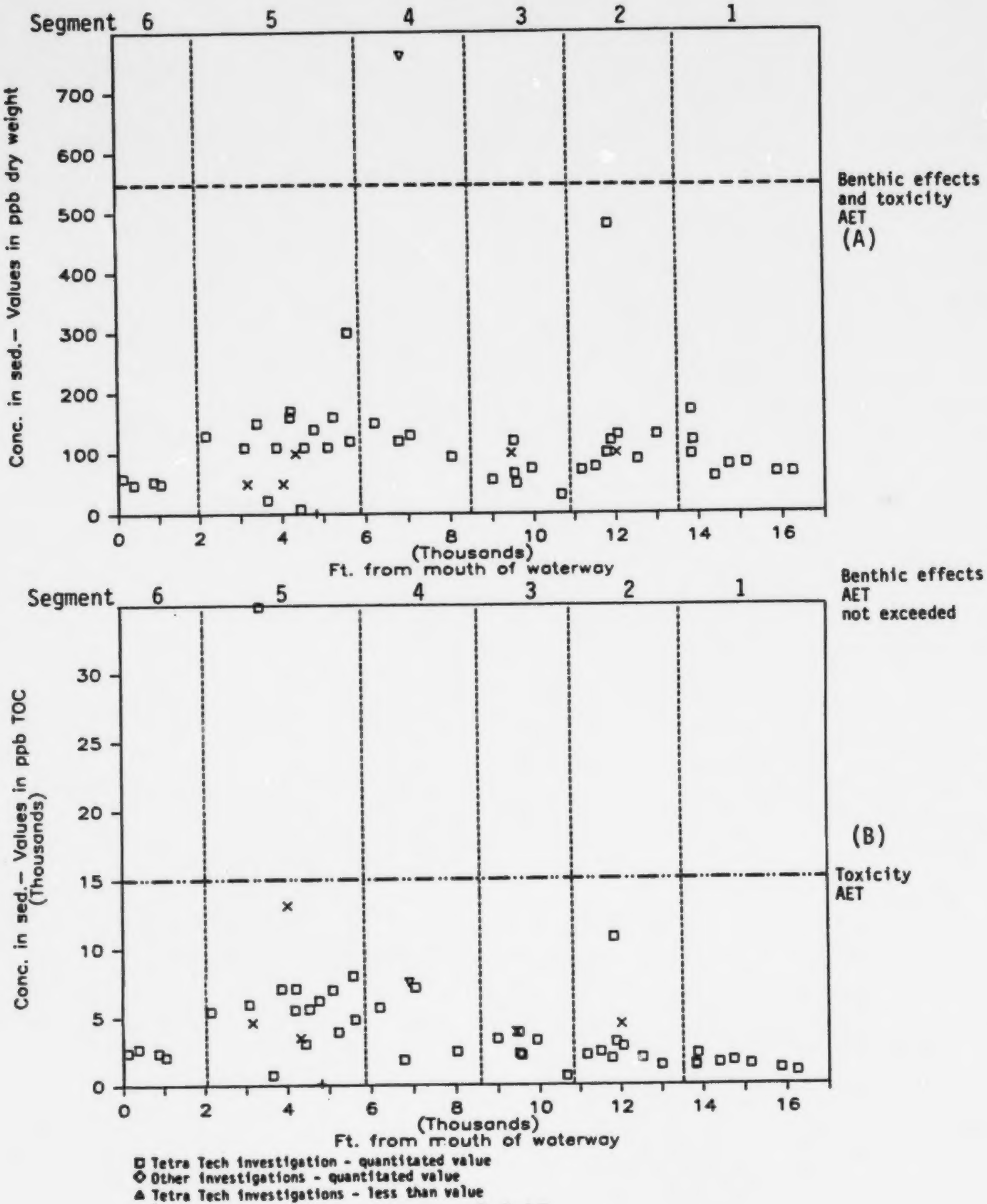


Figure 7.2.17

CONCENTRATIONS OF DIBENZOFURAN IN THE SURFICIAL SEDIMENTS OF THE HYLEBOS WATERWAY WITH DISTANCE FROM THE MOUTH OF THE WATERWAY
(A) Concentrations on a dry weight basis
(B) Concentrations normalized to total organic carbon content of the sediments

major sources of runoff (e.g., Hylebos Creek). The strong correlation between the distributions of dibenzofuran and LPAH (and to a lesser extent HPAH) discussed previously suggests that sources of LPAH in Hylebos Waterway probably sources of dibenzofuran (see PAH source identification discussion in Section 7.2.4.3).

7.2.5.4 Summary and Recommendations--

Dibenzofuran appears to be associated with the distribution of PAH (especially LPAH) in all areas of Commencement Bay. Contamination of sediments by dibenzofuran was greater in subsurface sediments than in surficial sediments. Confirmation of dibenzofuran sources would require substantially more source loading analyses than are currently available.

Future investigations of potential PAH sources should include analyses for dibenzofuran, since source identification efforts are hampered by the absence of data.

7.2.6 Benzyl Alcohol

7.2.6.1 Spatial Distribution--

The distribution of benzyl alcohol in surficial sediments of Hylebos Waterway is illustrated in Figure 7.2.18. Except for two samples with relatively high concentrations of the contaminant, benzyl alcohol was distributed homogeneously from the mouth to the head of the waterway. The two exceptions were samples from Stations HY-41 (Segment 5, 4,500 ft from the mouth) and HY-21 (Segment 2, 12,000 ft from the mouth). The former station was located along the south shore of the waterway, while the latter was in mid-channel. Neither area had been dredged within the past 10 yr.

The absence of a contamination gradient and the isolation of contamination to two sites distant from known point sources complicates source identification. The single sediment core sample taken in the area of concern (Station HY-61) had undetectable concentrations (<10 ug/kg) of benzyl alcohol in all horizons. This indicates either recent input of benzyl alcohol or degradation of the compound over time.

7.2.6.2 Loading Estimates--

No effort has been made to analyze any discharge to Hylebos Waterway for benzyl alcohol.

7.2.6.3 Source Identification--

In the absence of effluent and environmental data on benzyl alcohol, the most feasible way to identify potential sources was to determine types of industries with which benzyl alcohol may be associated. Benzyl alcohol has a variety of industrial uses, many of which are related to the dye and pigment industry (Hawley 1981):

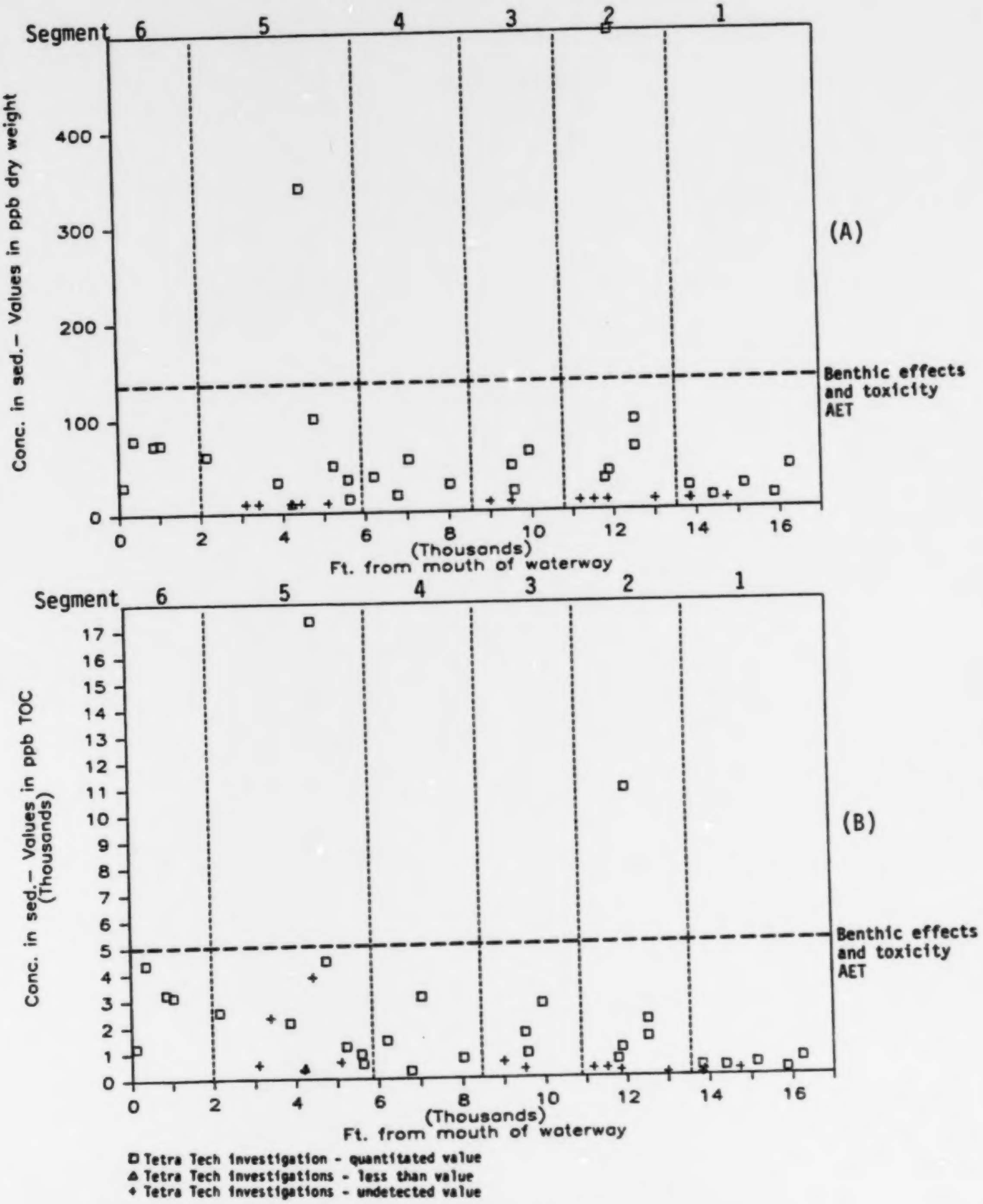


Figure 7.2.18

CONCENTRATIONS OF BENZYL ALCOHOL IN THE SURFICIAL SEDIMENTS OF THE HYLEBOS WATERWAY WITH DISTANCE FROM THE MOUTH OF THE WATERWAY
(A) Concentrations on a dry weight basis
(B) Concentrations normalized to total organic carbon content of the sediments

- Perfumes and flavors
- Photographic developer for color movie films
- Dyeing nylon filaments, textiles, and sheet plastics
- Solvent for dyestuffs, cellulose esters, casein, waxes, and other materials
- Heat-sealing polyethylene films
- Intermediate for benzyl esters, benzyl ethers, and benzyl bromide
- Bacteriostat
- Cosmetics, ointments, and emulsions
- Ballpoint pen inks
- Stencil inks.

In addition, benzyl alcohol is found in jasmine, hyacinth, yling-ylang oils, and at least two dozen other essential oils (Sax 1984).

None of the industries currently or historically in the areas of elevated sediment benzyl alcohol concentrations is known to handle dyes, inks, perfumes, or other products containing benzyl alcohol. The industries nearest the contaminated areas are Occidental Chemical Corporation, PRI Northwest, Pennwalt Corporation, and General Metals. Occidental and Pennwalt produce a variety of inorganic chemicals, PRI Northwest is a petroleum distributor, and General Metals is a scrap metal dealer. Since none of these industries or any other industry in the areas of contamination handle material containing benzyl alcohol, there are no known potential sources.

7.2.6.4 Summary and Recommendations--

A review of the industries in the areas of elevated contamination was unable to identify potential sources. Because benzyl alcohol is not a compound typically monitored by regulatory agencies, it may be an unidentified component of one or more discharges. Benzyl alcohol had been included among the compounds of concern in this investigation because it has been found in relatively high concentrations in the livers of some English sole collected from Hylebos Waterway. This observation and the lack of an apparent source suggest that benzyl alcohol may be a metabolic product.

Further efforts should be directed towards determining if the elevated concentrations of benzyl alcohol in fish tissue result from metabolic breakdown or transformation of another compound.

7.2.7 Chlorinated Hydrocarbons

7.2.7.1 Spatial Distribution--

Three groups of chlorinated hydrocarbons have been designated as contaminants of concern in Hylebos Waterway: chlorinated benzenes, chlorinated butadienes, and chlorinated ethenes. The spatial distributions of these contaminants in the surficial sediments of Hylebos Waterway are shown in Figures 7.2.19 - 7.2.24.

The concentrations of two representative chlorinated benzenes (hexachlorobenzene and 1,4-dichlorobenzene) in Hylebos Waterway sediments are shown in Figures 7.2.19A and 7.2.20A. Hexachlorobenzene and 1,4-dichlorobenzene showed an increased concentration (dry weight) at 4,000-4,500 ft from the mouth of the waterway (Segment 5). The decreases in concentration with distance from this area suggest the presence of a source in the immediate vicinity of the observed hot spot. This area of elevated contaminant concentrations was still evident after concentrations were normalized to the organic carbon content of the sediments (Figures 7.2.19B and 7.2.20B). The enrichment of these compounds in the organic material of these sediments indicated a nearby contaminant source. A local source of hexachlorobenzene and 1,4-dichlorobenzene located 3,000 - 4,000 ft from the mouth of the waterway and independent of major carbon sources is the most likely explanation for these data. There was no apparent cross-waterway contamination gradient in this area for either 1,4-dichlorobenzene or hexachlorobenzene, although there were no data available along the north shore of the waterway (Figure 7.2.21).

For both hexachlorobenzene and 1,4-dichlorobenzene, concentrations in sediments from a single station 12,000 ft from the waterway mouth were two to seven times greater than those from neighboring stations. This station was HY-22, noted earlier to be in an area where recent dredging has exposed contaminated sediments.

The spatial pattern of chlorinated butadiene contamination (Figures 7.2.22 and 7.2.23) was like that of the chlorinated benzenes, with a pronounced elevation at 4,000 ft from the waterway mouth on both a dry-weight and organic carbon-normalized basis. Hexachlorobutadiene concentrations (Figure 7.2.22) also increased at 12,000 ft (Station HY-22). The similarity in spatial patterns of contamination between the chlorinated benzenes and butadienes suggests a common source for both contaminant groups.

In December, 1981, Occidental Chemical Corporation sampled sediments in Hylebos Waterway Segment 5 from the southern shore out to the central channel (Candler 1982; Moore 1982). Total chlorinated butadiene concentrations ranged from 1,900 to 25,000 ug/kg along the southern shore of the waterway at about 3,200 ft from the mouth. More recent data shown in Figure 7.2.22 indicate substantially higher butadiene concentrations further offshore (up to 47,000 ug/kg).

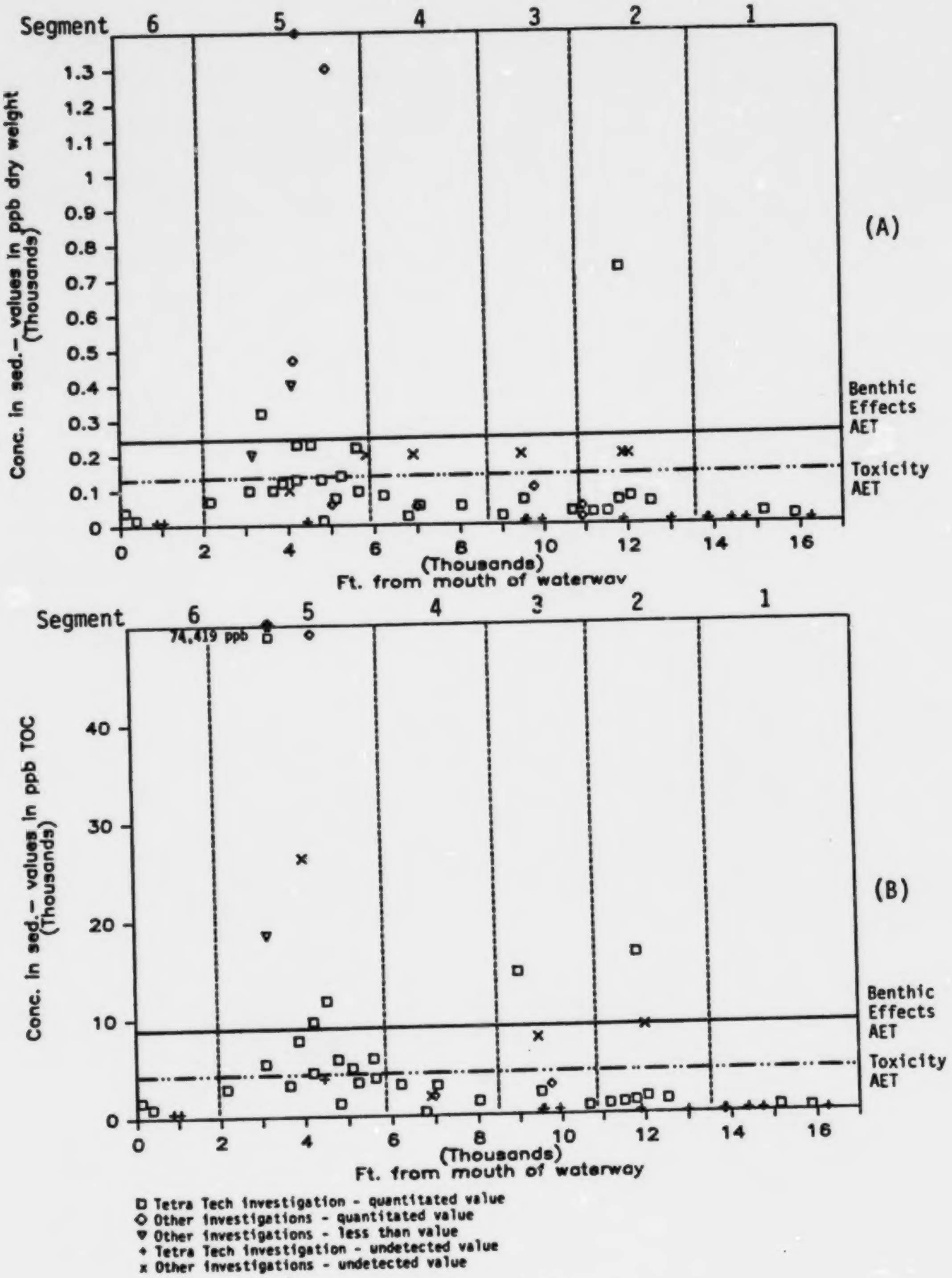


Figure 7.2.19

CONCENTRATIONS OF HEXACHLOROBENZENE IN THE SURFICIAL SEDIMENTS OF THE HYLEBOS WATERWAY WITH DISTANCE FROM THE MOUTH OF THE WATERWAY
(A) Concentrations on a dry weight basis
(B) Concentrations normalized to total organic carbon content of the sediments

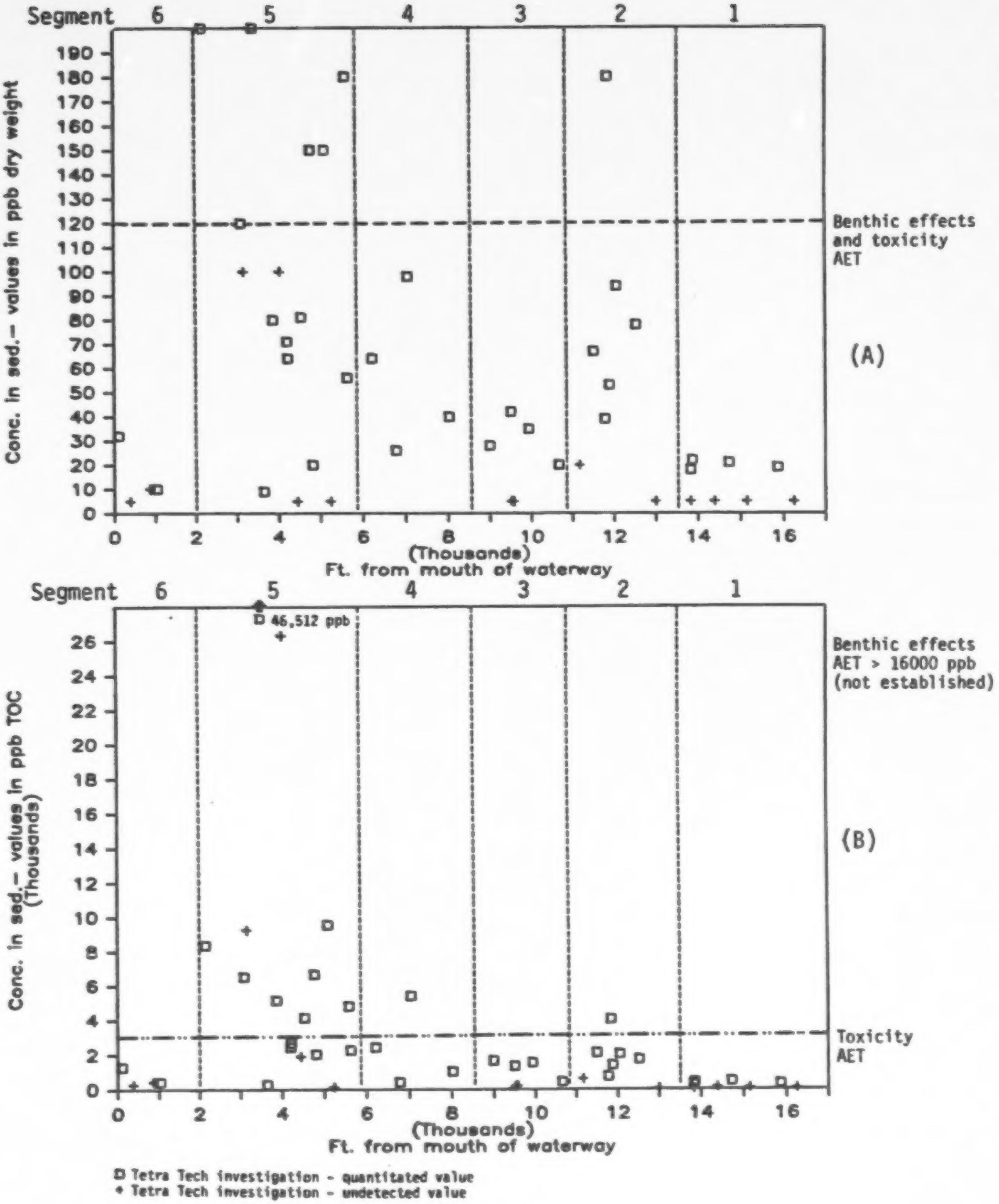
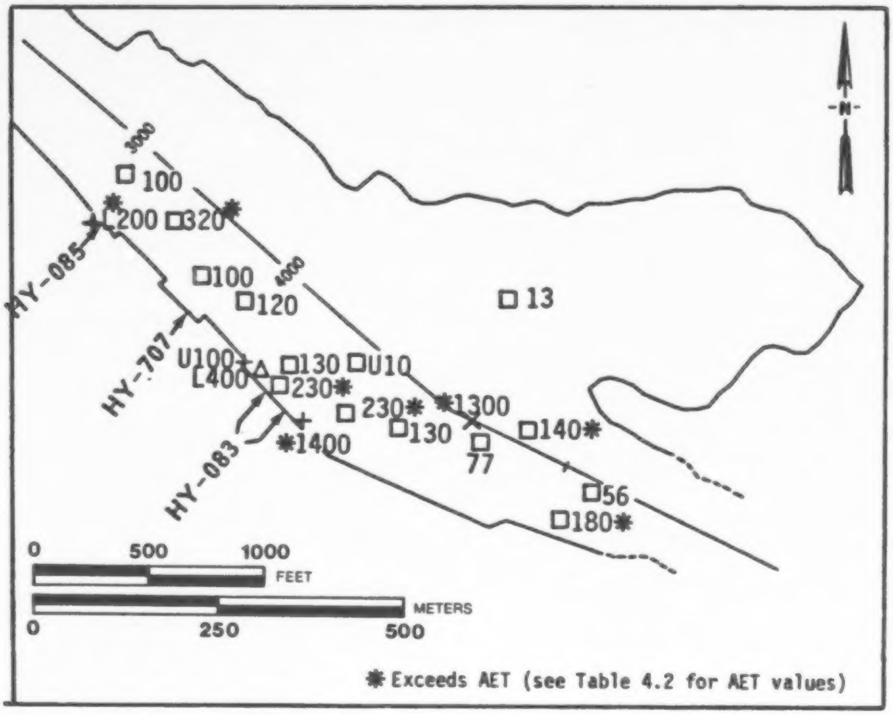


Figure 7.2.20

CONCENTRATIONS OF 1,4-DICHLOROBENZENE IN THE SURFICIAL SEDIMENTS OF THE HYLEBOS WATERWAY WITH DISTANCE FROM THE MOUTH OF THE WATERWAY
(A) Concentrations on a dry weight basis
(B) Concentrations normalized to total organic carbon content of the sediments



□ Tetra Tech survey data
△ EPA data
+ WDOE, 1984 data
x Data from other agencies

Figure 7.2.21

CONCENTRATIONS OF HEXACHLOROBENZENE
IN THE SURFICIAL SEDIMENTS OF HYLEBOS SEGMENT 5

(ug/kg dry weight)

U indicates undetected at value shown

L At least one of components of the group was undetected; sum includes the detection limit.

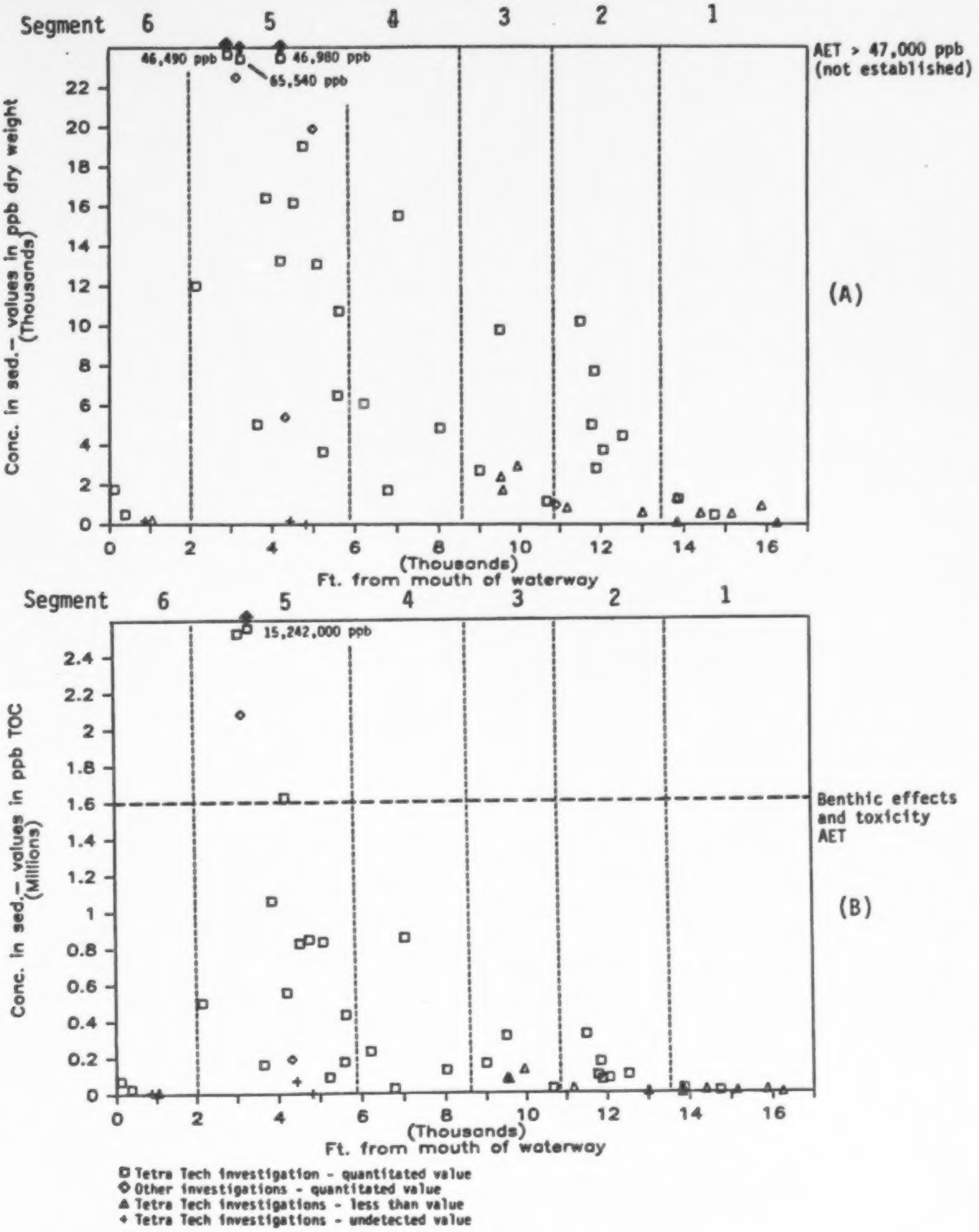


Figure 7.2.22

CONCENTRATIONS OF TOTAL CHLORINATED BUTADIENES IN THE SURFICIAL SEDIMENTS OF THE HYLEBOS WATERWAY WITH DISTANCE FROM THE MOUTH OF THE WATERWAY

(A) Concentrations on a dry weight basis
(B) Concentrations normalized to total organic carbon content of the sediments

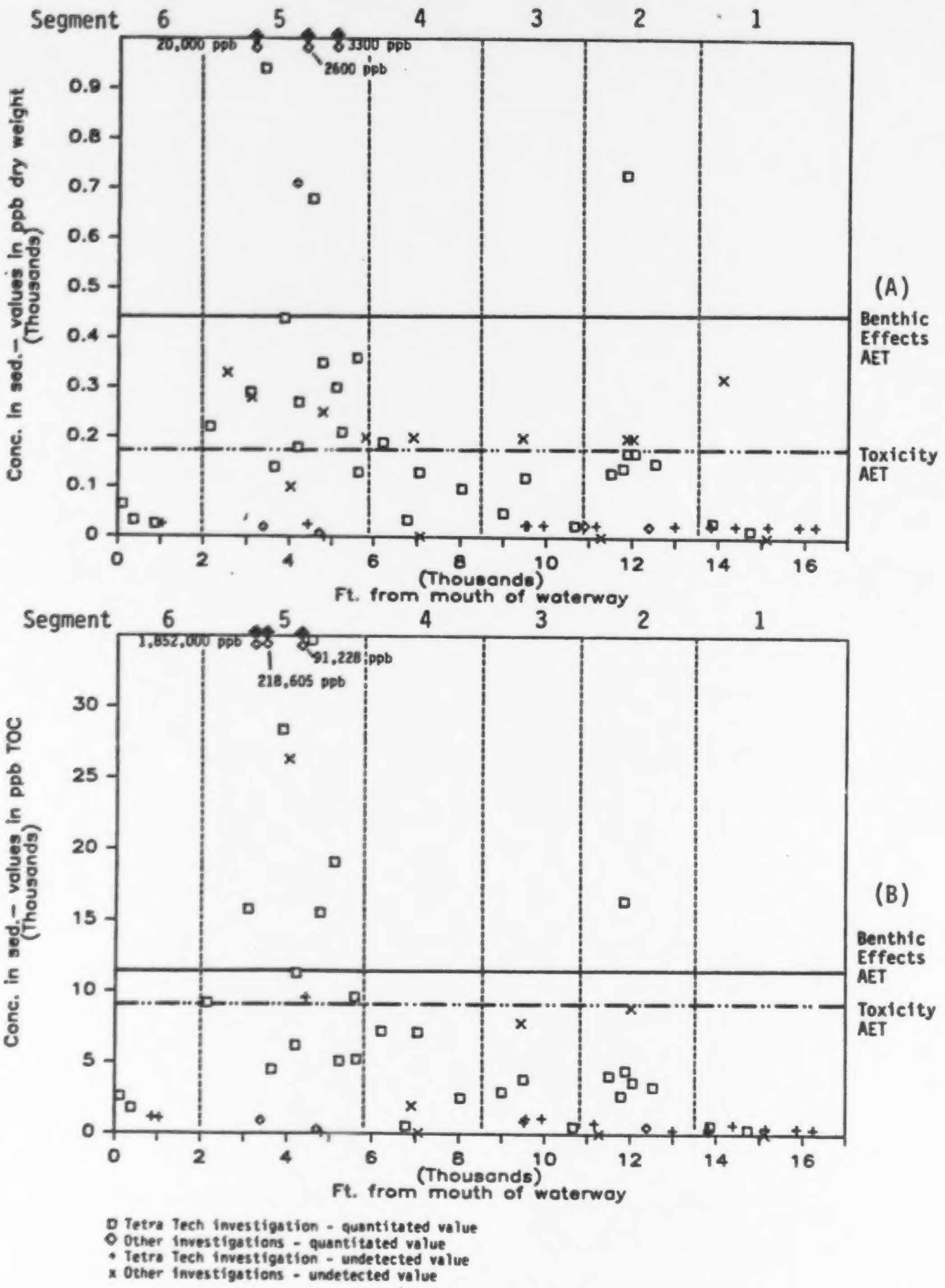


Figure 7.2.23

CONCENTRATIONS OF HEXACHLOROBUTADIENE IN THE SURFICIAL SEDIMENTS OF THE HYLEBOS WATERWAY WITH DISTANCE FROM THE MOUTH OF THE WATERWAY

(A) Concentrations on a dry weight basis
(B) Concentrations normalized to total organic carbon content of the sediments

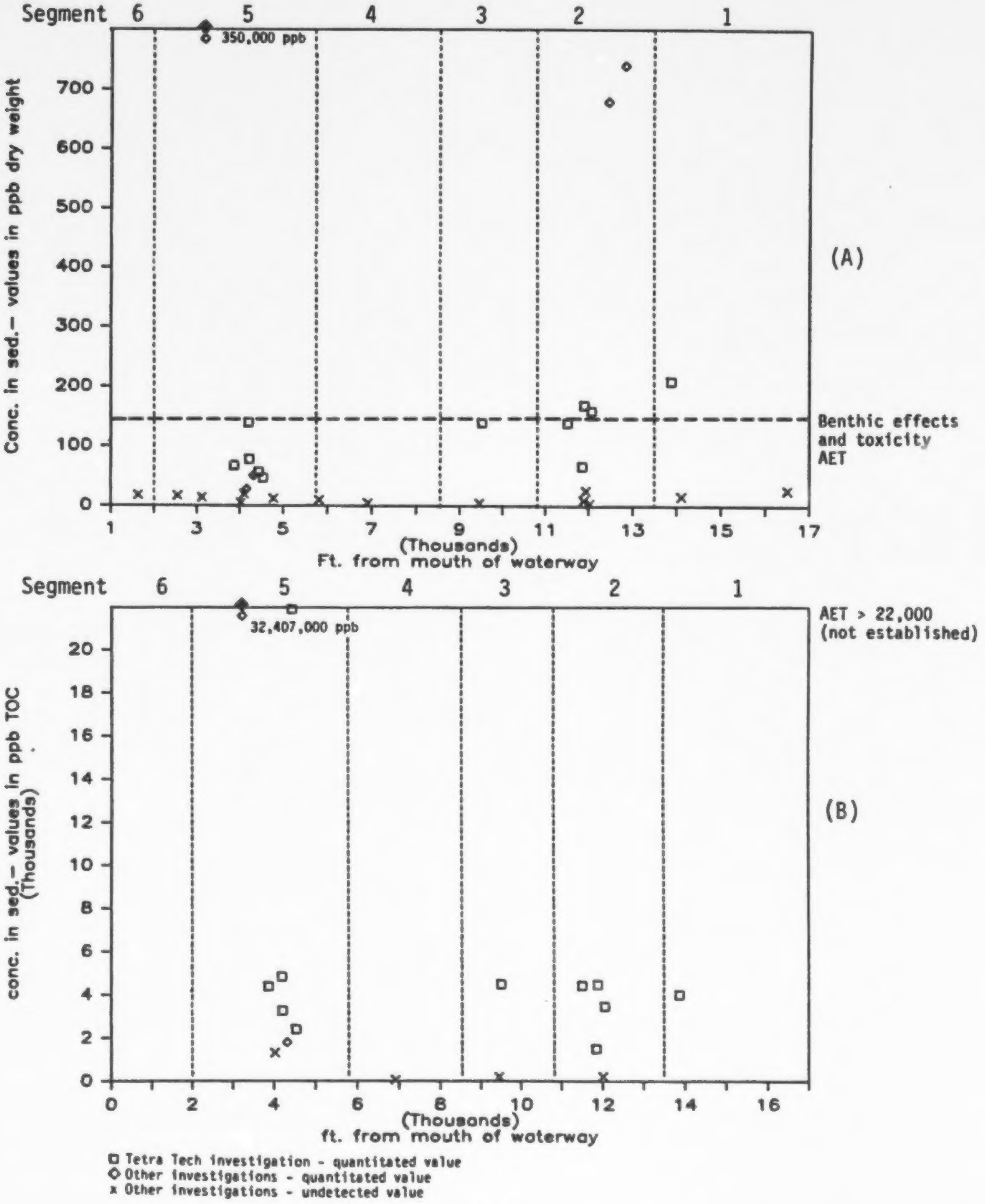


Figure 7.2.24

CONCENTRATIONS OF TETRACHLOROETHENE IN THE SURFICIAL SEDIMENTS OF THE HYLEBOS WATERWAY WITH DISTANCE FROM THE MOUTH OF THE WATERWAY
(A) Concentrations on a dry weight basis
(B) Concentrations normalized to total organic carbon content of the sediments

Only 11 surficial sediment samples within Hylebos Waterway were analyzed for chlorinated ethenes during the Tetra Tech survey, and only tetrachloroethene was detected (Figure 7.2.24). Tetrachloroethene concentrations were homogeneous among these stations, most of which were in the central waterway. Previous investigators have reported very high concentrations of tetrachloroethene in intertidal and shallow subtidal stations along the southern shore of the waterway about 3,000 and 12,500 ft from the mouth (Figure 7.2.24). WDOE (unpublished) reported 350,000 ug/kg in intertidal sediments along the southern shore of Hylebos Waterway 3,160 ft from the mouth. Candler (1982) reported up to 69,000 ug/kg in sediments from the same area. Occidental Chemical Corporation has monitored chlorinated ethenes in the water column of Hylebos Waterway 2,400 - 4,100 ft from the mouth. Concentrations of trichloroethene and tetrachloroethene have been as high as 232 and 72 ug/L, respectively (Conestoga-Rovers and Associates 1984a). The highest values were typically found along the southern shore of the waterway. There was some elevation of tetrachloroethene concentrations at 12,000 ft from the mouth, although not to the same degree as at the 3,000-ft area. As shown in Figure 7.2.24, Johnson and Prescott (1982) reported up to 740 ug/kg in intertidal sediments 12,500 to 13,000 ft from the waterway mouth.

The vertical distribution of chlorinated benzenes and butadienes is shown in Figures 7.2.25 and 7.2.26. The four sediment core samples (only three are shown) were all taken close to one another in Hylebos Waterway Segment 5, the area of greatest surficial sediment contamination. The vertical (temporal) patterns of contamination were not consistent among all cores, but two generalizations can be made. First, in most cores (including core HY-63, G01, not shown), the concentrations of chlorinated benzenes and butadienes increased with depth, indicating that contaminant input was greater historically than it is at present. Second, the relative proportion of tri-, tetra-, penta-, and hexachlorobutadienes varied with depth, suggesting that groundwater rising from deep aquifers is not a major source for these compounds. If it were, constant relative proportions of the butadienes would be expected throughout the sediment column. Although not shown, differences in the relative proportions of the various dichlorinated benzenes among the horizons also eliminate groundwater from deep aquifers as a source of these compounds. However, on the basis of the sediment core data alone, it is not possible to rule out shallow groundwater seeps along the waterway banks as potential sources.

The only sediment core data available for chlorinated ethenes is a single sample taken from the deepest horizon (0.66-0.81 m) at Station HY-63, G01. The sediment contained 330,000 ug/kg chlorinated ethenes, indicating either historical contamination or contamination via groundwater.

In summary, the spatial patterns of contamination of the chlorinated hydrocarbons suggest that the chlorinated benzenes and butadienes have a common source. The gradient of contamination along the length of the waterway suggests that this source is located at about 4,000 ft from the waterway mouth. The appearance of isolated hot spots along the southern shore of the waterway suggests that the source of at least the chlorinated

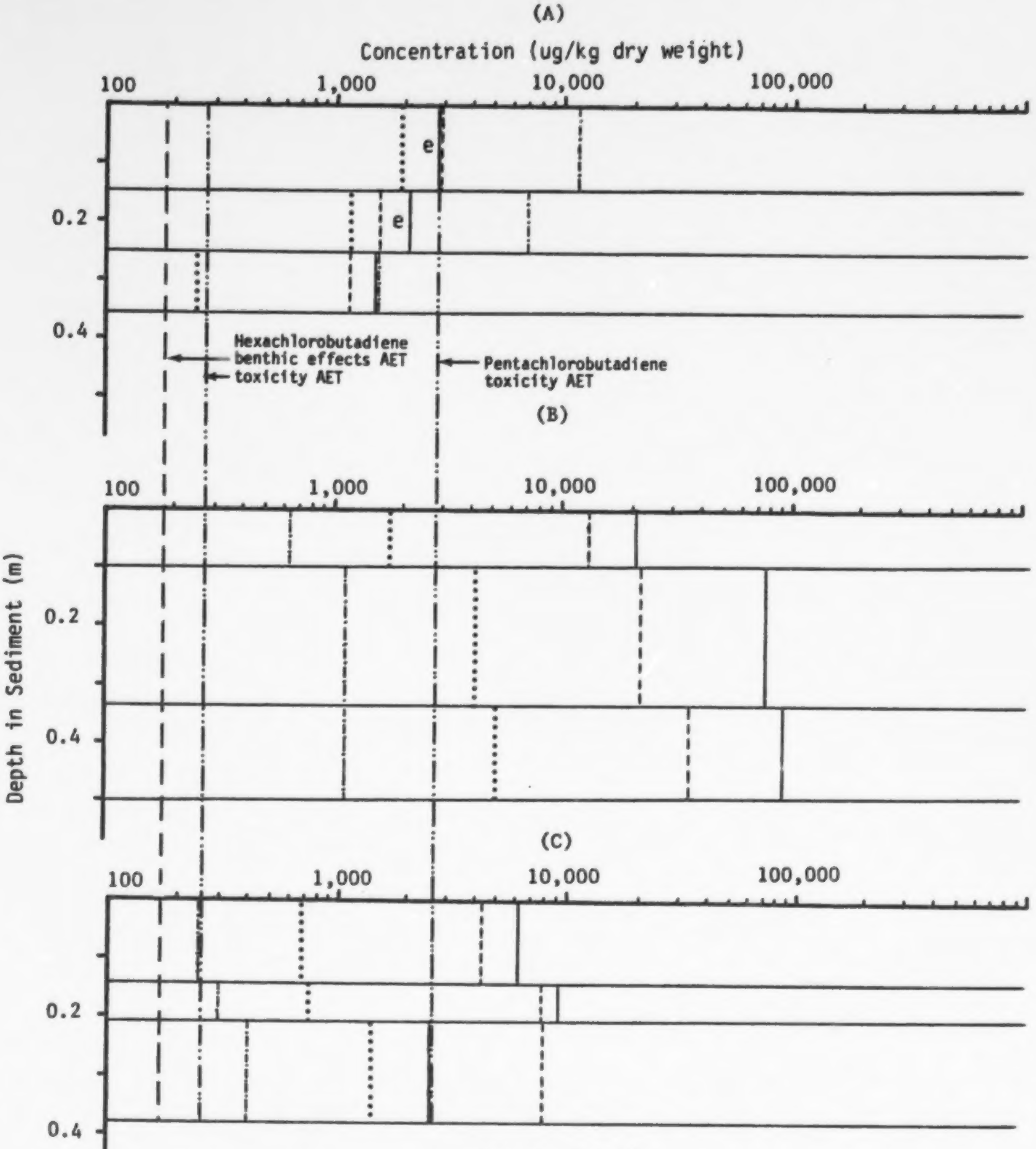


Figure 7.2.25

CONCENTRATIONS OF CHLORINATED BUTADIENES WITH
DEPTH IN THE SEDIMENT COLUMN
(A) STATION HY-63A, B01, (B) STATION HY-63B, B03;
(C) STATION HY-63C, B05

——— Trichlorobutadiene (no AET established)
----- Tetrachlorobutadiene (no AET established)
····· Pentachlorobutadiene (no benthic effects AET established)
-·-·- Hexachlorobutadiene

e = estimated concentration

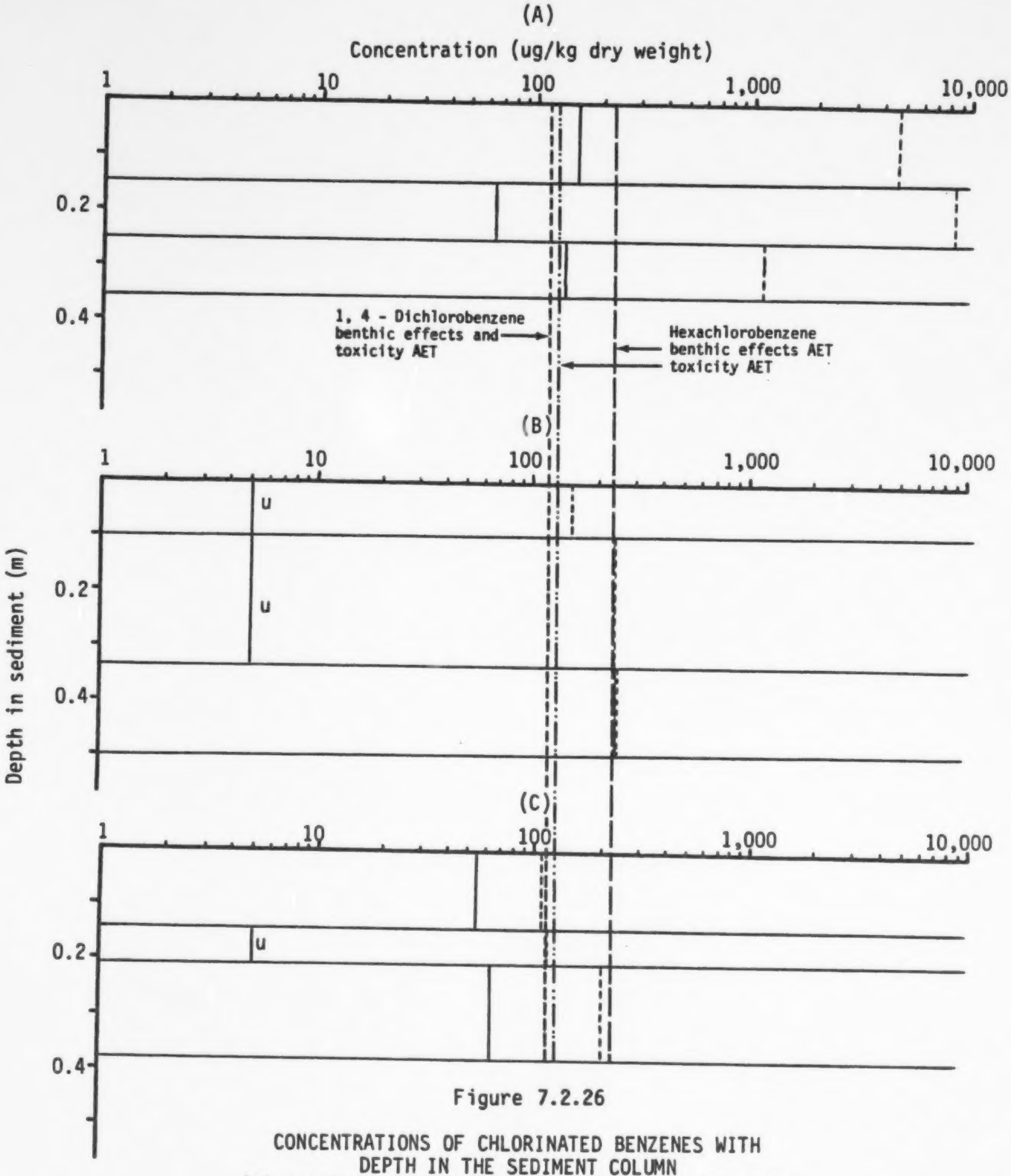


Figure 7.2.26

CONCENTRATIONS OF CHLORINATED BENZENES WITH DEPTH IN THE SEDIMENT COLUMN
(A) STATION HY-63A, B01; (B) STATION HY-63B, B03;
(C) STATION HY-63C, B05

—— 1,4-dichlorobenzene
----- hexachlorobenzene

u = undetected at detection limit shown

butadienes may be located along this shoreline. Groundwater from the deeper aquifiers does not appear to be the major route of contaminant migration.

The chlorinated ethenes had relatively uniform concentrations in the central portion of the waterway, although there have been several reports of localized high concentrations in intertidal sediments about 4,000 ft and, to a lesser extent, about 12,000 ft from the waterway mouth. Based upon the horizontal and vertical contamination data alone, it is not possible to establish whether the route of contaminant migration is via industrial effluent, surface water runoff, or shallow groundwater.

7.2.7.2 Loading Estimates--

Loadings from discharges to Hylebos Waterway with detectable concentrations of the chlorinated hydrocarbons of concern are summarized in Tables 7.2.4 and 7.2.5. Despite extensive sampling, few discharges were found to contain measurable concentrations of chlorinated ethenes, chlorinated benzenes, or chlorinated butadienes. Two groups of discharges require discussion because of relatively high loading of chlorinated hydrocarbons: those associated with Occidental Chemical Corporation (HY-707, HY-083, HY-085, groundwater), with a total chlorinated hydrocarbons loading of 6.6 lb/day, and those associated with the Pennwalt Corporation (HY-700, HY-701, HY-058, HY-054, shallow and intermediate aquifers), with a total chlorinated hydrocarbon loading of 1 lb/day.

Four discharges listed in Tables 7.2.4 and 7.2.5 are associated with Occidental Chemical Corporation: the main plant effluent (HY-707), pipes protruding from a bulkhead on the Occidental waterfront (HY-085), and groundwater discharge beneath the facility (Areas 2 and 3). Loading of chlorinated ethenes from groundwater beneath Occidental is the largest identified in Table 7.2.4. Groundwater beneath Occidental was estimated to contribute about 6 lb/day chlorinated ethenes. (The method of calculating chlorinated ethene loading and the locations of Areas 2 and 3 are discussed further in Section 7.2.7.3). Of this 6 lb/day, 1.5 lb/day was tetrachloroethene; the remainder was trichloroethene. It is not clear why only tetrachloroethene was found in the surficial sediments of Hylebos Waterway during the Tetra Tech survey, when the groundwater beneath Occidental and most other sources of chlorinated ethenes contributes both tri- and tetrachloroethene. Presumably it is a function of the greater solubility and lower sediment adsorption of the trichloroethene.

Loading of chlorinated ethenes from the Occidental Chemical Corporation main effluent (0.65 lb/day) is also among the largest identified in Table 7.2.4. This loading is based on a single observation of 5 ug/L chlorinated ethenes during a WDOE Class II survey (Yake 1980). The main effluent is also identified as a source of chlorinated benzenes and butadienes. Both hexachlorobenzene (30 ug/L) and hexachlorobutadiene (9 ug/L) have been detected in the chlorine stripper effluent, which ultimately is discharged through the main effluent outfall.

Table 7.2.4

CHLORINATED ETHENES: SUMMARY OF LOADINGS FROM DISCHARGES TO HYLEBOS WATERWAY

Drain #	Drain Name	Flow (MGD) (Avg. and Range) (# of Observations)	Period of Observations for Contaminant Concentrations	Concentration (ug/l) (Avg. and Range) (# of Observations)	Loading (lbs/day) (Avg. and Range)	Compounds Detected
INDUSTRIAL DISCHARGES						
HK-052	Kaiser Ditch	1.9 (0.23-2.9) (n=8)	9/23/80-8/17/81	3.3 (2-5) (n=3)	0.052	trichloroethene tetrachloroethene
HY-058	Pennwalt Main Outfall	11 (9.4-12) (n=2)	6/3/80-6/2/81	10 (4-15) (n=2)	0.92	trichloroethene tetrachloroethene
HY-707	Occidental Main Effluent	15.49 --- (n=1)	9/25/79	5 --- (n=1)	0.65	trichloroethene tetrachloroethene
DRAINS AND RUNOFF						
HM-028	Morningside Ditch	0.66 (0.49-0.78) (n=3)	9/24/80	1 --- (n=1)	0.0055	tetrachloroethene
HY-054	East Channel Ditch	0.0055 (0.0014-0.01) (n=3)	9/23/80-6/2/81	11 (4-17) (n=2)	0.00050	trichloroethene tetrachloroethene
HY-056	Six-inch Concrete Pipe	0.017 (0.0043-0.029) (n=2)	6/30/80-8/13/81	240 (52-754) (n=2)	0.034	trichloroethene tetrachloroethene
HY-083	Two Seeps at Occidental	0.0051 (0.0002-0.01) (n=2)	4/18/84	L 3.5 (L 3 - L 4) (n=2)	L 0.00015	trichloroethene tetrachloroethene
HY-085	Seven Steel Pipes	0.0007 --- (n=1)	9/23/80-4/18/84	270 (83-450) (n=2)	0.0016	trichloroethene tetrachloroethene

Table7.2.4(cont'd)

GROUNDWATER BANK SEEPS						
HY-700	Pennwalt East Seep	0.00079 (0.00036-0.0014) (n=3)	6/3/80-4/18/84	930 (94-4,830) (n=4)	0.0061	trichloroethene tetrachloroethene
HY-701	Pennwalt West Seep	0.0012 (0.001-0.0014) (n=2)	9/23/80-8/13/81	241 (143-395) (n=3)	0.0024	trichloroethene tetrachloroethene
HYLEBOS CREEK						
HC-000	Hylebos Creek WDOE Station 17	16 (4.9-44) (n=15)	8/17/81	2 (n=1)	0.27	trichloroethene
GROUNDWATER BENEATH PENNWALT						
Shallow Aquifer		0.00090 (0.00078-0.0010)	4/81-9/81	L 1,100	L 0.009[a]	tetrachloroethene
Intermediate Aquifer		0.0045 (0.0025-0.0066)	4/81-9/81	L 2,045	L 0.11[a]	tetrachloroethene
GROUNDWATER BENEATH OCCIDENTAL						
Area 2		0.0014	12/79-9/84	313,000 (202,000-529,000) (n=14)	3.7[b] (2.4-6.2)	trichloroethene tetrachloroethene
Area 3		0.0016	12/79-9/84	165,000 (8,000-299,000) (n=14)	2.2[b] (0.11-3.9)	trichloroethene tetrachloroethene

NOTES: L indicates less than

[a] Loading estimated from data in AWARE (1981), see text

[b] Loading estimated by procedures in Walker Wells (1980a), see text

The following discharges have been sampled and found not to contain chlorinated ethenes (numbers in parentheses indicate number of analyses and detection limits): HC-130 (1, 1 ug/l), HY-016 (1, 1 ug/l), HY-017 (1, unspecified), HY-018 (1, 4 ug/l), HY-021 (1, 10 ug/l), HY-023 (1, 10 ug/l), HY-040 (1, 1 ug/l), HY-061 (1, 1 ug/l), HY-066 (3, 1-10 ug/l), HY-071 (1, unspecified), HY-073 (1, 1 ug/l), HY-076 (1, 10 ug/l), HY-078 (2, 1 ug/l), HY-704 (2, unspecified), HY-709 (2, 1 ug/l).

Table 7.2.5

CHLORINATED BENZENES AND BUTADIENES: SUMMARY OF LOADINGS FROM DISCHARGES TO HYLEBOS WATERWAY

CHLORINATED BENZENES

Drain #	Drain Name	Flow (MGD) (Avg. and Range) (# of Observations)	Period of Observations for Contaminant Concentrations	Concen-tration (ug/l) (Avg. and Range) (# of Observations)	Loading (lbs/day) (Avg. and Range)	Compounds Detected
INDUSTRIAL DISCHARGES						
HY-707	Occidental Main Effluent	15.49 --- (n=1)	9/25/79	0.3 --- (n=1)	0.039	hexachlorobenzene
HYLEBOS CREEK						
HC-000	Hylebos Creek WDOE Station 17	16 (4.9-44) (n=15)	11/7/83	L 3 --- (n=1)	L 0.40	1,3-dichlorobenzene
DRAINS AND RUNOFF						
HM-028	Morningside Ditch	0.66 (0.49-0.78) (n=3)	8/17/81-11/7/83	L 38 (2 - L 85) (n=2)	L 0.21 (0.11 - L 0.47)	1,2-dichlorobenzene 1,3-dichlorobenzene 1,4-dichlorobenzene 1,2,4-trichlorobenzene
HY-085	Seven Steel Pipes at Occidental	0.0007 --- (n=1)	9/23/80	L 11 --- (n=1)	L 0.00006 ---	1,2-dichlorobenzene 1,3-dichlorobenzene
GROUNDWATER BANK SEEPS						
HY-700	Pennwalt East Seep	0.00079 (0.00036-0.0014) (n=3)	9/23/80	9 --- (n=1)	0.000059 ---	1,2,4-trichlorobenzene

NOTE: The following discharges have been sampled and found not to contain chlorinated benzenes (numbers in parentheses indicate number of analyses and detection limits): HC-130 (1, 1 ug/l), HK-052 (13, 1-10 ug/l), HY-016 (1, 1 ug/l), HY-017 (1, unspecified), HY-018 (1, 0.5-8 ug/l), HY-021 (1, 10 ug/l), HY-023 (1, 10 ug/l), HY-040 (1, 1 ug/l), HY-054 (3, 1-10 ug/l), HY-056 (1, unspecified), HY-058 (1, unspecified), HY-061 (1, 1 ug/l), HY-062 (1, 1 ug/l), HY-066 (3, 1-10 ug/l), HY-070 (1, 1 ug/l), HY-071 (1, unspecified), HY-073 (1, 1 ug/l), HY-076 (1, 10 ug/l), HY-078 (2, 1 ug/l), HY-083 (2, 1 ug/l), HY-700 (3, 1 ug/l), HY-701 (1, 1 ug/l), HY-704 (2, unspecified), HY-709 (1, unspecified).

Table7.2.5(cont'd)

CHLORINATED BUTADIENES

INDUSTRIAL DISCHARGES						
HY-707	Occidental Main Effluent	15.49 --- (n=1)	9/25/79	0.2 --- (n=1)	0.026	hexachlorobutadiene
DRAINS AND RUNOFF						
HY-085	Seven Steel Pipes at Occidental	0.0007 --- (n=1)	9/23/80-4/18/84	3.5 (2-5) (n=2)	0.000020 (0.000012-0.000029)	trichlorobutadiene tetrachlorobutadiene hexachlorobutadiene
GROUNDWATER BANK SEEPS						
HY-700	Pennwalt East Seep	0.00079 (0.00036-0.0014) (n=3)	9/23/80-4/18/84	6 (5-7) (n=3)	0.000040 (0.000033-0.000046)	hexachlorobutadiene
HY-701	Pennwalt West Seep	0.0012 (0.001-0.0014) (n=2)	9/23/80-6/2/81	L 5 (L 1-9) (n=2)	L 0.00005 (L 0.00001-0.00009)	hexachlorobutadiene

NOTES: The following discharges have been sampled and found not to contain chlorinated butadienes (numbers in parentheses indicate number of analyses and detection limits): HC-000 (5, 1-20 ug/l), HC-130 (1, 1 ug/l), HK-052 (11, 1-10 ug/l), HM-028 (6, 1-20 ug/l), HY-016 (1, 1 ug/l), HY-018 (1, 8 ug/l), HY-021 (1, 10 ug/l), HY-023 (1, 10 ug/l), HY-040 (1, 1 ug/l), HY-054 (4, 1-10 ug/l), HY-056 (2, 1 ug/l), HY1-058 (1, unspecified), HY-062 (1, 1 ug/l), HY-062 (1, 1 ug/l), HY-066 (3, 1-10 ug/l), HY-070 (1, 1 ug/l), HY-071 (1, unspecified), HY-076 (1, 10 ug/l), HY-078 (2, 1 ug/l), HY-083 (2, 1 ug/l), HY-709 (2, 1 ug/l)

L indicates less than

The Pennwalt main outfall (HY-058) is a known source of chlorinated ethenes (0.92 lb/day), although concentrations of chlorinated benzenes and butadienes have been below detection limits.

Four discharges shown as known sources are associated with groundwater beneath the Pennwalt Corporation property: the East Seep (HY-700), the West Seep (HY-701), and the shallow and intermediate aquifers. The Pennwalt seeps are sources of chlorinated benzenes, chlorinated ethenes, and chlorinated butadienes (Osborne 1980a, 1980b). Chlorinated ethene loadings from the shallow and intermediate aquifers have been estimated from chloroform loading as discussed in Section 7.2.6.3. The values shown should be considered as approximate upper limits; actual loading could be significantly lower.

Hylebos Creek is indicated as a source of chlorinated ethenes in Table 7.2.4 because of a single observation of 2 ug/L trichloroethene (WDOE unpublished). It is listed as a source of chlorinated benzenes because of a single observation of <3 ug/L 1,3-dichlorobenzene (WDOE unpublished). The fact that the contaminated sediments were distant from the point of discharge of Hylebos Creek indicates that the creek is not responsible for the observed contamination in the areas of concern. Chlorinated benzene loading from the Morningside Ditch (HM-028) is based on a concentration of <38 ug/L. Chlorinated benzene concentration has, on at least one occasion, exceeded this value (<85 ug/L; WDOE unpublished). It is unknown if this represented a single occurrence or an unidentified sporadic discharge. Nevertheless, Morningside Ditch discharges to Hylebos Waterway on the north shore and the area with elevated chlorinated benzenes is along the south shore. Therefore, Morningside Ditch is probably not the source of the observed contamination.

7.2.7.3 Source Identification--

The distribution of both chlorinated benzenes and butadienes in the surficial sediments of Hylebos Waterway suggests the presence of a source in Segment 5, about 4,000 ft from the mouth of the waterway. Given its proximity to the contaminated area and its known discharges of the compounds, this source is the Occidental Chemical Corporation.

The chlorinated ethenes have not been found at elevated concentrations within surficial sediments of the central waterway, although localized hot spots have been reported in intertidal and shallow subtidal areas along the southern shoreline. These hot spots have been found in Hylebos Waterway Segment 5, about 3,200 ft from the waterway mouth, and Segment 2, about 12,500 ft from the mouth. Occidental Chemical Corporation and Pennwalt Corporation are the major sources for these contaminants in Segments 5 and 2, respectively, based on their proximity to the hot spots and known discharges of the chlorinated ethenes. Occidental Chemical Corporation and Pennwalt Corporation are discussed individually below.

Occidental Chemical Corporation--Occidental Chemical Corporation occupies the south shore of Hylebos Waterway between 3,100 and 4,400 ft from the mouth of the waterway. Chlorinated hydrocarbons, particularly the chlorinated ethenes, have been produced at the Occidental Chemical Corporation facility either as a product or a by-product of past and present industrial practices. Two independent manufacturing practices at the plant can be identified as potential sources of chlorinated ethenes, benzenes, and butadienes: (1) the production of chlorine and caustic soda by electrolysis of sodium chloride brine and (2) operation of the solvents production facility.

The chlorinated ethenes are considered by-products from the use of graphite anodes in the production of chlorine (AWARE 1981). Chlorinated benzenes are a by-product in the manufacture of chlorine gas by electrolysis of brine (Konasewich et al. 1982). Hexachlorobutadiene is used by chlorine producers, to recover chlorine from "snift" gas (U.S. EPA 1980a). Occidental currently uses a sodium hypochlorite countercurrent system for this purpose (Monahan, F., personal communication); past practices have not been determined.

The manufacture of chlorine and sodium hydroxide by electrolysis began at the Occidental Chemical Corporation site in February, 1929 with the opening of the Tacoma plant, and continues to the present time. Historically, the anode used in this electrolytic process was made of graphite impregnated with linseed oil to prevent deterioration. (The firm has replaced some of the graphite anodes with titanium anodes.) Reaction of free chlorine with the linseed oil in the graphite results in the production of a number of chlorinated organic by-products. These chlorinated organic compounds leave the electrolytic cell along with the chlorine gas and are processed by direct and/or indirect cooling (Figure 7.2.27). At this point, the waste stream is split into two components. One portion continues through drying, compression, and purification processes. The second component is directed to a chlorine stripper for recovery of remaining chlorine gas. From 1929 to 1969 or 1970, effluents from both the chlorine purification unit and the chlorine stripper were discharged directly to Hylebos Waterway through the main effluent (Boys and Sceva 1979). Since 1969 or 1970, the chlorinated organics from the chlorine purification unit have been taken out-of-state for incineration and have not been released to Hylebos Waterway (Boys and Sceva 1979). The effluent from the chlorine stripper continues to be discharged to Hylebos Waterway along with the total plant effluent.

It is difficult to estimate the concentration or loading of chlorinated organics in the Occidental Chemical Corporation effluent over the 40 yr during which effluent from both the chlorine purifying unit and chlorine stripper was discharged to Hylebos Waterway. In 1979, 50-75 gal/day of chlorinated organic wastes were generated by the chlorine purifying unit at Occidental (Boys and Sceva 1979). However, historical volumes may have been much lower because production capacity was probably smaller. It may be possible, by analysis of the wastes from the chlorine purifying unit and review of plant records, to determine the historical composition of this waste stream and loading estimates of the individual components.

Recent information is available regarding effluent from the chlorine stripper. Yake (1980) reported that the chlorine stripper effluent contained a variety of chlorinated organics including tetrachloroethene (30 ug/L), hexachlorobenzene (30 ug/L), and hexachlorobutadiene (9 ug/L). These concentra-

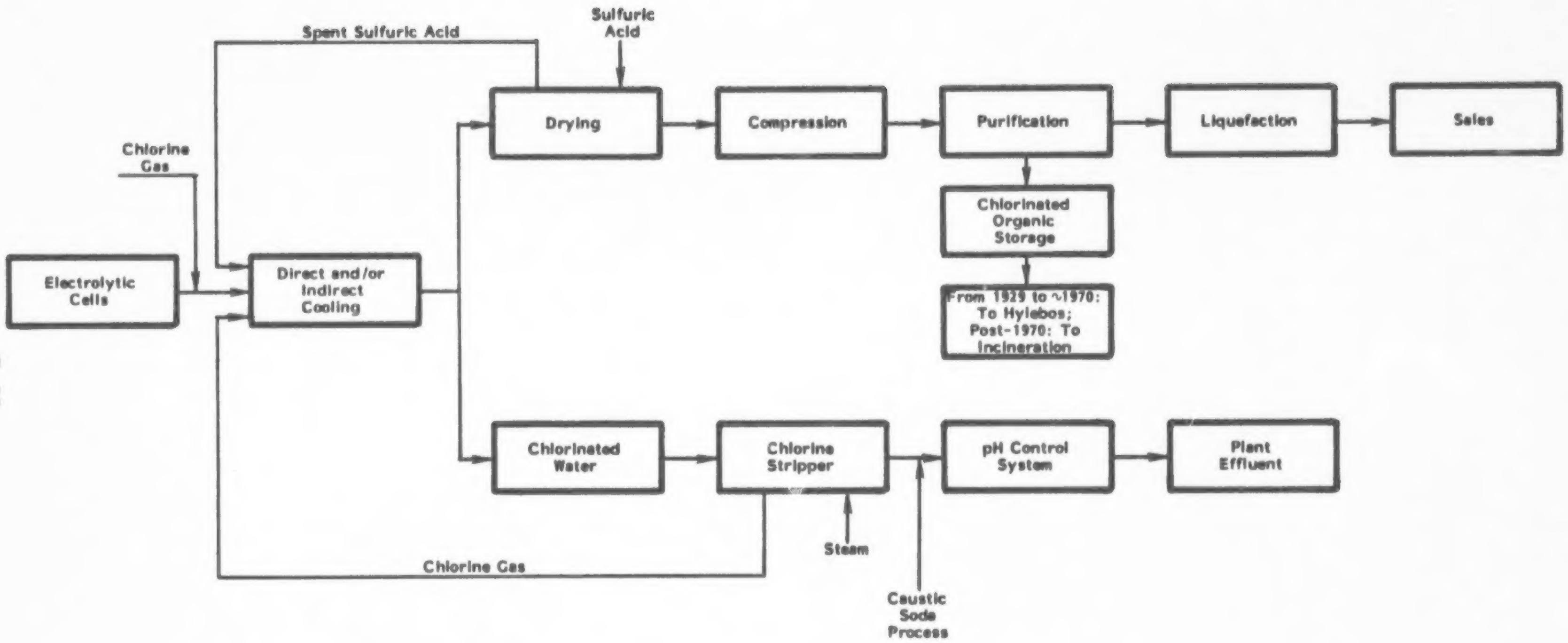


Figure 7.2.27

FLOW SCHEMATIC OF CHLORINE PRODUCTION AND CHLORINATED ORGANIC WASTE HANDLING AT OCCIDENTAL CHEMICAL CORPORATION (Modified from OCC, 1984a) tions were reduced by dilution in the total plant effluent to 4, 0.3, and 0.2 ug/L, respectively.

A second potential source of chlorinated organic compounds at Occidental Chemical Corporation was the solvents plant. This facility produced trichloroethene and tetrachloroethene between January, 1947 and May, 1973. The plant produced about 500 tons/yr of "Generator and Stripper Lime" waste that consisted of calcium chloride, excess lime, inert inorganic solids, and chlorinated organic compounds (Boys and Sceva 1979). Occidental Chemical Corporation has estimated that the solids in this waste contained 3,000 - 4,000 ppm chlorinated organic compounds (Feller 1981). Contaminants associated with this waste include dichloromethane, chloroform, carbon tetrachloride, trichloroethene, and tetrachloroethene (Walker Wells 1980a). Hexachlorobutadiene, a by-product of the manufacture of chlorinated ethenes (U.S. EPA 1975), could also have been among the chlorinated organic compounds in the wastes.

The Occidental Chemical Corporation solvent plant began operation in 1947. Its waste disposal history (Boys and Sceva 1979) is as follows:

1947-approximately 1950	All wastes discharged to Hylebos Waterway.
1950-approximately 1952	Wastes discharged to pond located along northwest plant boundary, now occupied by salt pad. Liquid decanted to Hylebos Waterway.
1952-1972	Wastes discharged to lime barge moored in Hylebos Waterway. Liquids decanted overboard to Hylebos Waterway. Solids barged to Commencement Bay deep-water disposal site.
1972-April, 1972	Wastes discharged to one of two pits in southwest corner of plant property. Liquids decanted to Hylebos Waterway. Solids trucked Tacoma Municipal Landfill.
May, 1972-June, 1972	Wastes discharged to above pits. Liquids decanted to Hylebos Waterway. Solids trucked to "Petarcik" site, 2.5 km west of Fife.
June, 1972-May, 1973	Wastes discharged to above pits. Liquids decanted to Hylebos Waterway. Solids trucked to "General Metals" site on north shore of upper Hylebos Waterway and "Don Oline" property, 0.8 km southeast of Occidental plant.
May, 1973	Plant operation terminated.

To assess the extent of chlorinated organic contamination on plant property as a result of solvents plant operation, Occidental Chemical Corporation contracted Walker Wells, Inc. and Hart-Crowser and Associates to conduct groundwater and soil chemistry studies on the plant property and on adjacent Port of Tacoma land to the northwest. Results of this work have been released in a series of documents (e.g., Hart-Crowser 1980a; Walker Wells 1980a,b). Groundwater quality measurements made at 12 sites throughout the area (Figure 7.2.28) organic compounds in the vicinity of wells 1, 4, 7, 10, 11, and 12, with total chlorinated organics concentration reaching about 700 mg/L. The chlorinated organic compounds with the greatest concentrations in groundwater were methylene chloride, chloroform, chlorinated ethanes, and chlorinated ethenes. Hexachlorobutadiene was detected in a single well (#4) at up to 960 ug/L. Chlorinated benzenes were undetected at 10 ug/L (Walker Wells 1980b, Appendix B). Contamination was observed in the shallowest wells (24 ft) down to a depth of at least 115 ft (Site 4). In general, concentrations of chlorinated organics decreased with depth (Walker Wells 1980b). Walker Wells (1980a) estimated that 19,000 - 35,000 lb of chlorinated organic compounds were contained in the saturated zone beneath the Occidental facility. Using the percentage composition provided by Walker Wells (1980a, Appendices D and E) for each compound within the chlorinated organic group, trichloroethene constitutes an estimated 9,000 - 15,000 lb of this total, while tetrachloroethene constitutes an estimated 900 - 1,500 lb.

To refine the location of chlorinate organic hot spots in the unsaturated zone, Hart-Crowser and Associates collected soil samples from 69 test pits and auger holes (Hart-Crowser and Associates 1980a,b; Walker Wells 1980a). Samples were concentrated in three areas where chlorinated organics would most likely be found on the basis of historical industrial practices. The areas sampled are shown in Figure 7.2.28 and include Area 1, beneath the construction storage/parking lot at the site of an old settlement pond; Area 2, in the vicinity of the old solvents plant, solvents plant sludge pits, and abandoned trichloroethene tanks; and Area 3, surrounding an old trichloroethene tank. Areas 2 and 3 were the most contaminated, with one Area 2 sample containing a chlorinated organics concentration of 20,000 mg/kg. Concentrations of chlorinated organic compounds generally increased with depth down to 7 - 8 ft, the lower limit of sampling. Hart-Crowser and Associates (1980b) estimated that 10,724 lb of chlorinated organic compounds were contained in the unsaturated zone within these three areas, most of which (9,363 lb) was in Area 2.

As a result of these investigations of the unsaturated zone, the WDOE ordered Occidental Chemical Corporation to remove all soils in Areas 2 and 3 containing over 150 mg/kg chlorinated organic compounds and to cover all areas in excess of 15 mg/kg with an impermeable material (Docket No. DE 81-153). These actions have been completed, and it has been estimated that the excavation resulted in removal of 9,368 lb (or 87.4 percent) of the total chlorinated organics previously quantified (Walker Wells 1980b). No action was taken on the contaminated groundwater because of the ineffectiveness of existing removal/treatment technology, and because dilution calculations indicated only a small impact on receiving water column quality (Walker Wells 1980b; unreferenced status report in WDOE Occidental Chemical Corporation files).

Since removal of the contaminated solids in Areas 2 and 3 in 1981, Occidental Chemical Corporation has continued to monitor groundwater quality in three wells on a quarterly basis. (A fourth well was monitored through February, 1982, but monitoring was discontinued since contaminant concentrations were typically all below the detection limit of 1 ug/L). Trends in groundwater quality in Well 4 beneath Area 2 (see Figure 7.2.28), based on quarterly analytical reports submitted to WDOE by Occidental, are shown in Figure 7.2.29. Trichloroethene concentrations have not shown a consistent trend since removal of the overlying contaminated soils in the spring of 1981. Tetrachloroethene and total chlorinated hydrocarbons (chlorinated ethenes, chloroform, and methylene chloride) concentrations have increased in groundwater. Average chlorinated hydrocarbon concentrations in Well 1 beneath Area 3 have also shown an increasing trend (64 ug/L before soil removal; 533 mg/L after soil removal). Contaminant concentrations in Well 7 near Area 1 have decreased (223 ug/L before soil removal; 71 ug/L after soil removal). In general, the soil removal ordered by WDOE has not yet resulted in a noticeable improvement in groundwater quality. However, a rapid improvement should not be expected given the low permeability of the water-bearing materials (Walker Wells 1981).

The data discussed above were used to calculate the chlorinated ethene loading presented in Table 7.2.4. Averages of all tri- and tetrachloroethene concentration measurements from December, 1979 to September, 1984 were calculated for Well 1 (representative of Area 3) and Well 4 (representative of Area 2). Groundwater discharge rates taken from Walker Wells (1980a) were then used to calculate loadings. The procedure used to calculate loadings followed that of Walker Wells (1980a), with the exception that their contaminant concentrations were based only on the July, 1980 data, a date when contaminant concentrations were relatively low.

Hylebos Segment 2 - Pennwalt Corporation--An area of elevated chlorinated ethene concentrations was located in Hylebos Segment 2 at 12,000 ft from the mouth of the waterway, corresponding to the portion of waterway bordered to the south by Pennwalt Corporation. Pennwalt has been located at its present site along Hylebos Waterway since the 1920s. The plant produced chlorine, sodium hydroxide, chlorate salts, and herbicides, and, except for herbicides, continues to produce these materials.

The chlorinated organic compounds created at Pennwalt as by-products of chlorine production are separated from the chlorine gas during passage through cooling towers. Pennwalt historically discharged the condensate, containing chlorinated organic compounds and residual chlorine, to on-site evaporation lagoons in an area known as Taylor Lake (see Figure 7.2.30). Graphite wastes from the anodes, which were likely to have been contaminated with chlorinated organic compounds, were historically disposed of in the Taylor Lake area (AWARE 1981).

As a consequence of these past waste disposal practices, groundwater beneath the Pennwalt facility has become contaminated by a variety of chlorinated organic compounds. From April to September, 1981, AWARE, Inc. conducted a groundwater quality survey on the Pennwalt property. Initial sampling

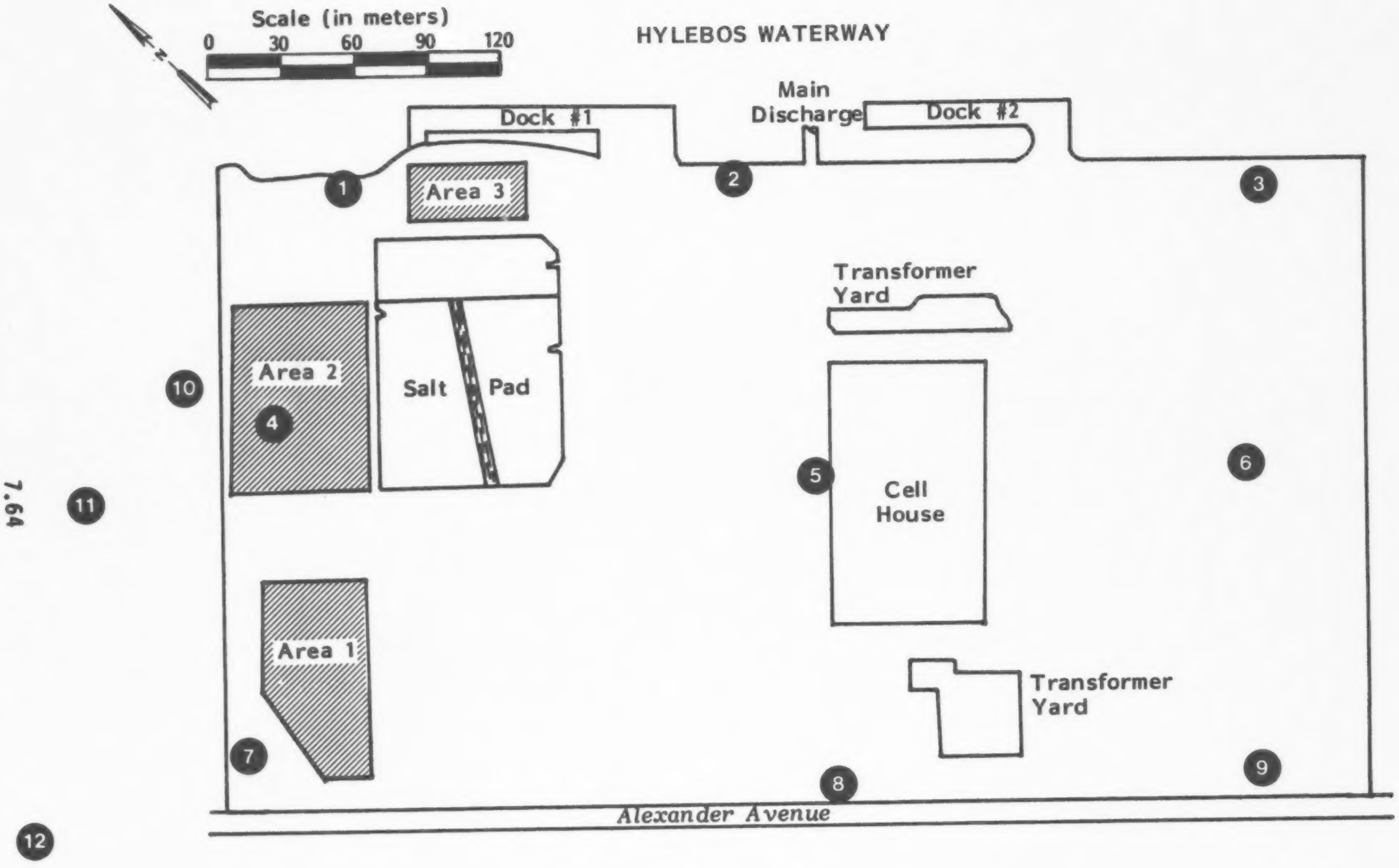
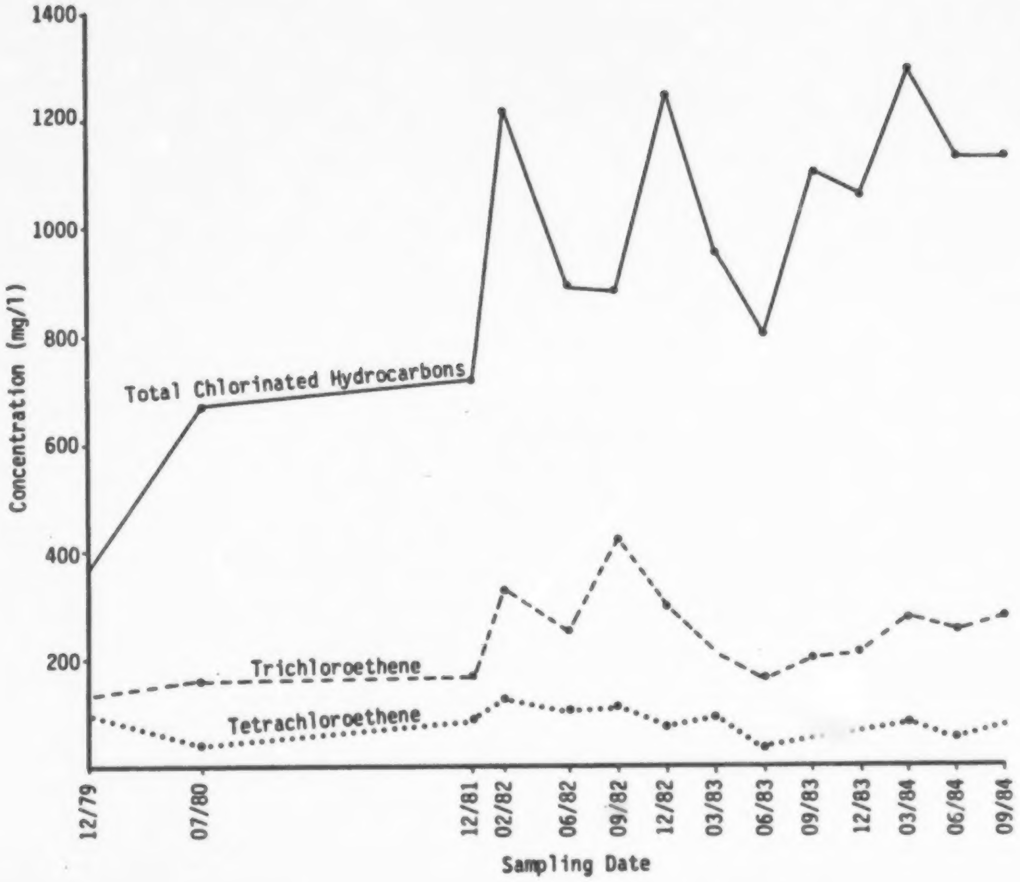


Figure 7.2.28

LOCATION OF GROUNDWATER MONITORING WELLS
AT OCCIDENTAL CHEMICAL CORPORATION



NOTE: DATA SHOWN ARE FROM WELL NO.4, LOCATED IN AREA 2. SAMPLES WERE COLLECTED AT SCREENED DEPTHS OF 45 FT. SAMPLE COLLECTED 12/79 WAS ANALYZED BY CAN TEST. ALL OTHER SAMPLES WERE ANALYZED BY OCCIDENTAL CHEMICAL CORPORATION.

Figure 7.2.29.

CONCENTRATION OF CHLORINATED ORGANIC COMPOUNDS IN GROUNDWATER BENEATH OCCIDENTAL CHEMICAL CORPORATION.

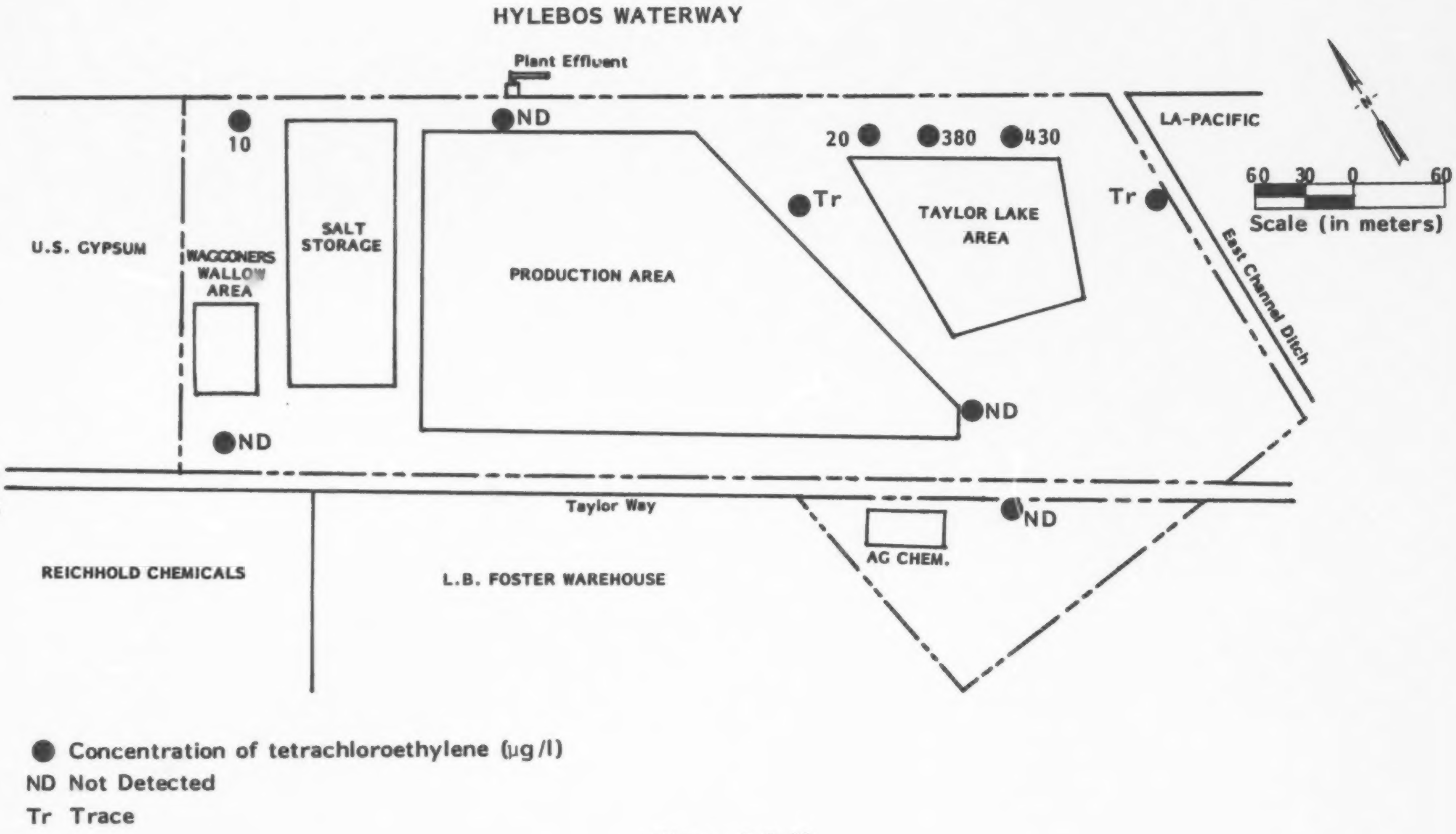


Figure 7.2.30

CONCENTRATIONS OF TETRACHLOROETHENE IN GROUNDWATER MONITORING WELLS ON THE PROPERTY OF PENNWALT CORPORATION. (Data from AWARE, 1981) was restricted to an intermediate aquifer (15-20 ft deep) and a deep aquifer (45 ft deep). Chemical analyses of groundwater in these aquifers indicated elevated concentrations of arsenic, chromium, and volatile organic compounds (chloroform, carbon tetrachloride, chlorinated ethanes, and chlorinated ethenes). Among the compounds identified to be of concern in the present investigations (chlorinated ethenes, chlorinated benzenes, and chlorinated butadienes), only tetrachloroethene was consistently found in elevated concentrations. The concentrations of tetrachloroethene in various monitoring wells on the Pennwalt property are shown in Figure 7.2.30, indicating that the contamination was generally restricted to the area between Taylor Lake and Hylebos Waterway. Subsequent sampling of a shallow aquifer (10 ft deep) and additional sampling of the intermediate and deep aquifers by AWARE indicated that contamination of groundwater by tetrachloroethene was generally restricted to the shallow and intermediate aquifers. Trichloroethene was only detected in trace amounts, while chlorinated benzenes were undetected. Hexachlorobutadiene was detected in a single well north of Taylor Lake at 16 ug/L. Its occurrence was attributed to historical disposal of solvents in the Taylor Lake area (AWARE 1981).

Chlorinated ethenes were not compounds of major concern in the AWARE surveys and the data are inadequate to directly compute tetrachloroethene loadings. Samples were frequently not analyzed for tetrachloroethene in the most contaminated areas, samples were lost, or only composite samples were taken. However, tetrachloroethene loading may be estimated indirectly using data for chloroform, a compound of major concern in the AWARE studies and one for which a great deal of groundwater quality data are available. During the AWARE studies, 64 samples were analyzed for both chloroform and tetrachloroethene. Of these, 24 had concentrations of both compounds below detection limits. Concentrations of both compounds in the remaining 40 samples are shown in Table 7.2.6 and Figure 7.2.31. Chloroform and tetrachloroethene concentrations were frequently elevated in samples from the same stations. Tetrachloroethene concentrations were typically less than half those of chloroform. A direct linear relationship between the two compounds could not be established, largely because of the single outlier (chloroform = 5,840 ug/L, tetrachloroethene = 180 ug/L), shown in Figure 7.2.31. Chloroform and tetrachloroethene were by-products of the same chlorine production process at Pennwalt, disposed in the same manner (on-site lagoons in the Taylor Lake area), and have similar environmental fate processes (primarily volatilization; Callahan et al. 1979). Therefore it is possible to use the concentration of one compound to predict, or at least place constraints on, that of the other.

AWARE (1981) determined an average chloroform concentration in the groundwater contaminant plume north of Taylor Lake and, along with estimates of discharge rate, estimated groundwater chloroform loading in the shallow (0.014-0.018 lb/day) and intermediate (0.085-0.22 lb/day) aquifers. If the tetrachloroethene concentration is considered to be half or less that of chloroform, the tetrachloroethene loading via groundwater can be estimated at less than 0.009 lb/day from the shallow aquifer and less than 0.11 lb/day from the intermediate aquifer. Actual loadings could be considerably less. While the absence of data preclude calculating a more precise loading for

Table 7.2.6

AWARE (1981) GROUNDWATER SAMPLES CONTAINING CHLOROFORM AND/OR TETRACHLOROETHENE CONCENTRATIONS ABOVE DETECTION LIMITS

Sampling Round	Monitoring Well	Chloroform Concentration (μg/l)	Tetrachloroethene Concentration (μg/l)
First	PW-1C	1,300	430
	PW-2C	1,800	380
	PW-3C	170	20
	PW-4C	160	10
	PW-5C	<10	<10
	PW-6C	<10	<10
	PW-7C	<10	<10
	PW-8C	<10	<1
	PW-9C	<10	<1
	PW-10C	<10	<1
	PW-11C	<10	<1
Second	PW-2S-LT-2	2,700	860
	PW-2S-HT-2	5,840	180
	PW-3S-LT-2	390	<0.01
	PW-3S-HT-2	160	0.4
	PW-4S-LT-2	9	<0.01
	PW-4S-HT-2	43	<0.01
	PW-5S-LT-2	3	<0.01
	PW-6S-LT-2	4	<0.01
	PW-6S-HT-2	<2	0.01
	PW-7S-HT-2	2	0.01
	PW-8S-HT-2	<2	2.5
	PW-9S-LT-2	<2	0.01
	PW-9S-HT-2	<2	1
	PW-10S-HT-2	<2	0.4
	PW-11S-HT-2	<2	0.4
	PW-12S-HT-2	590	340
	PW-2D-LT-2	2	0.9
	PW-3D-LT-2	2	0.3
	PW-4D-LT-2	310	0.1
	PW-4D-HT-2	68	<0.01
	PW-5D-HT-2	3	0.01
	PW-6D-LT-2	<2	0.01
	PW-10D-LT-2	2	0.01
	PW-12D-HT-2	8	18
Third	PW-4SS-HT	996	<0.01
	PW-4SS-LT	408	<0.01
	PW-6SS-HT	840	20
	PW-6SS-LT	835	10
	PW-10SS-LT	16	0.6

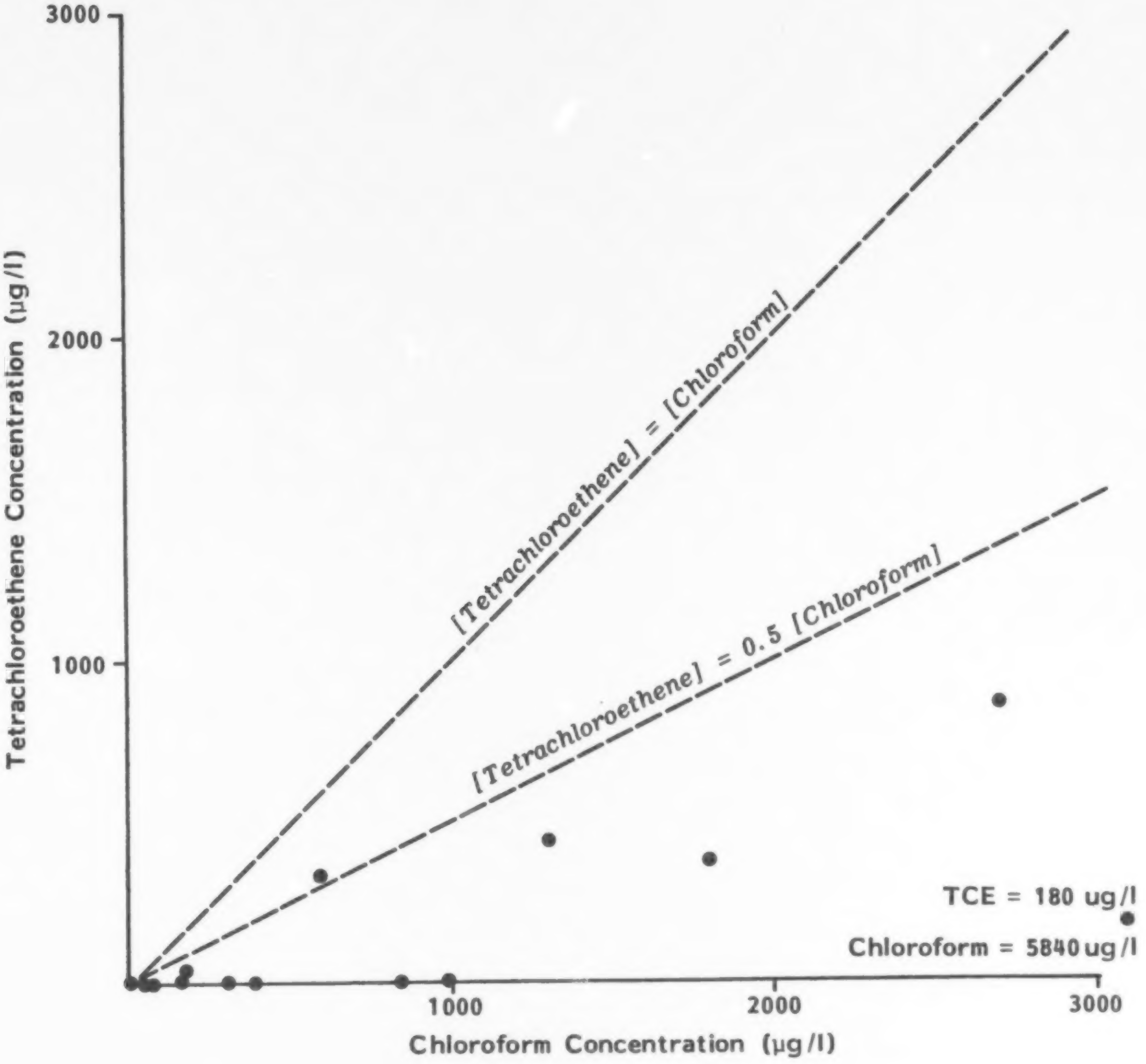


Figure 7.2.31

RELATIONSHIP BETWEEN CHLOROFORM AND TETRACHLOROETHENE CONCENTRATIONS IN GROUNDWATER BENEATH THE PENNWALT PROPERTY (Data from AWARE, 1981) the compound, the above exercise places reasonable upper limits on actual loadings.

Contamination of groundwater at Pennwalt by chlorinated organic compounds is a consequence of historical rather than current disposal practices. Since 1981, the chlorine condensate, previously disposed in the on-site lagoons, been passed through a chlorine stripper and discharged to Hylebos Waterway through the main outfall (Yake 1981). A single analysis of the main outfall effluent after this rerouting of the chlorine condensate did not detect measurable levels of chlorinated ethenes (Yake 1982a; detection limits unspecified). The graphite anodes impregnated with linseed oil that had historically been used were replaced with titanium anodes in 1975 (High, O., personal communication), thereby reducing production of chlorinated organic by-products.

7.2.7.4 Summary and Recommendations--

Based on review of the existing data, Occidental Chemical Corporation appears to be the major source of the chlorinated benzenes and butadienes found in Hylebos Waterway sediments. A single sediment station with elevated chlorinated benzene and butadiene concentrations off Pennwalt Corporation was located where buried sediments had probably been recently exposed by dredging. It is unknown whether contamination of these previously buried sediments can be attributed to Pennwalt, Occidental, or some other source. Discharge of chlorinated benzenes has been documented from Morningside Ditch and Hylebos Creek, although the spatial gradient of contamination strongly suggests that Occidental is the major source.

Both Pennwalt Corporation and Occidental Chemical Corporation are sources of tri- and/or tetrachloroethene. Based on both the extent of sediment contamination and calculated loadings, Occidental appears to be the larger of the two sources. These compounds have been released from the facilities through both groundwater and the main plant outfalls. Although localized contamination of intertidal sediments by chlorinated ethenes has been found at both Pennwalt and Occidental, the distribution of chlorinated ethenes in sediments of the central waterway appears relatively homogeneous. Extensive sampling throughout the waterway has not been conducted for these volatile compounds. Findings pertinent to Occidental and Pennwalt are summarized below.

Occidental Chemical Corporation--Occidental Chemical Corporation is the major source of the chlorinated organics compounds of concern to Hylebos Waterway for the following reasons:

- An increase in concentrations of chlorinated organic compounds in waterway sediments adjacent to the facility as compared to concentrations throughout the remainder of the waterway

- The fact that Occidental is the only industry, both presently and historically, in the area of greatest contamination

- A greater estimated loading of chlorinated benzenes, butadienes, and ethenes to Hylebos Waterway from this facility than from any other along the length of the waterway
- The documented discharge of a variety of industrial process effluents directly into the Hylebos Waterway, all of which could contain one or more of the contaminants of concern
- Detection of all chlorinated organic compounds of concern in the main plant discharge
- Contamination of soil on the plant property by chlorinated organic compounds as a result of past spills and waste disposal practices
- Contamination of groundwater beneath the plant property by chlorinated ethenes
- Detection of chlorinated ethenes in water samples collected from Hylebos Waterway near the facility.

Based on the production history of Occidental Chemical Corporation, discharge of chlorinated organic compounds to Hylebos Waterway was probably greater in the past than it is at present. Until the early 1970s, chlorinated organic compounds were released to Hylebos Waterway via discharges from the chlorine purifying unit, the chlorine stripper, the solvents plant, and groundwater. The groundwater and the chlorine stripper effluent (via the main outfall) still introduce chlorinated organic compounds to the waterway. A decrease in chlorinated organic discharge over time is reflected in most of the sediment core samples taken off Occidental.

At the present time, chlorinated organic compounds are reaching Hylebos Waterway sediments from both the main Occidental outfall (chlorinated benzenes, butadienes, and ethenes) and through groundwater (chlorinated ethenes). Documentation of the chlorinated benzenes and butadienes in the main plant outfall is based on the 1979 Class II survey. Additional analysis is recommended.

The WDOE has started to address the problem of groundwater contamination by ordering removal of contaminated soil and covering of the contaminated areas with an impermeable material (asphalt). Although contaminants already in the saturated zone will continue to reach the waterway, these actions should result in a continued improvement in groundwater quality with time. However, as of late 1984 (3 yr after remedial action), no improvement in groundwater quality was evident and continued monitoring appears warranted.

Pennwalt Corporation--Pennwalt appears to be responsible for the chlorinated ethene contamination of intertidal sediments in upper Hylebos Waterway, for the following reasons:

- An increase in the sediment concentrations of chlorinated ethenes in Hylebos Waterway adjacent to the facility
- Detection of chlorinated ethenes in water samples collected from Hylebos Waterway adjacent to the facility (Osborne 1980)
- The production of the chlorinated compounds of concern during chlorine production at the facility
- Detection of chlorinated ethenes in groundwater beneath the facility and/or in groundwater seeps along the facility's waterfront
- Detection of chlorinated ethenes in the main plant effluent.

Chlorinated ethenes have migrated from the facility to the waterway via three principal routes: discharge via the main outfall effluent, stormwater runoff from on-site waste ponds, and groundwater discharge from the shallow and intermediate aquifers. Cessation of discharges to the on-site waste ponds in 1981 should have reduced the release of contaminants by surface water runoff.

Contamination via groundwater continues as a consequence of historical disposal of wastes in the Taylor Lake area. Groundwater is currently a potential source of chlorinated ethenes to Hylebos Waterway, although not to the extent as groundwater is at Occidental. Based on detection of hexachlorobutadiene in groundwater and seeps along the waterfront, it appears that this compound is also entering the waterway via groundwater, although the loading estimates do not indicate that this is a major source. If remedial action is taken, efforts should first be directed towards removing the sources of the contamination at Pennwalt. These efforts should include a determination of the magnitude and areal extent of contamination in the sludges of Taylor Lake, and the removal of the most contaminated materials.

The following recommendations may help focus additional source investigations in Hylebos Waterway for chlorinated hydrocarbons (i.e., benzenes, butadienes, and ethenes):

- Analyze the main plant discharges at Occidental and Pennwalt to better quantify their importance as contaminant sources. If Occidental is confirmed as an ongoing source of chlorinated benzenes and butadienes, as suggested herein, then the in-plant sources of these compounds to the waste stream should be eliminated. This probably would involve replacement of the graphite anodes currently used.
- Continue monitoring groundwater beneath Occidental, which is the largest contributor of chlorinated ethenes to Hylebos Waterway. Evaluate available groundwater treatment technologies for their potential application on the Occidental property.

- Consider assessing the extent of contamination in sludges disposed at Taylor Lake at Pennwalt and the feasibility of removing contaminated material.
- Evaluate resuspension of contaminated sediments directly off the dock at Occidental when reviewing future dredging permit applications in the area.

Of the chlorinated hydrocarbons identified to be of concern in Hylebos Waterway, chlorinated ethenes have the greatest solubility. This suggests that source controls implemented at Pennwalt would be particularly effective in improving sediment quality in Hylebos Waterway. Were the sources of chlorinated ethenes eliminated, a decrease in chlorinated ethene concentrations in sediments of the waterway could be expected in a relatively short period of time. Both the chlorinated benzenes and butadienes are more persistent than are the chlorinated ethenes. Therefore, sediment removal, as well as source control, may be necessary for these compounds.

7.2.8 Pentachlorocyclopentane Isomer

7.2.8.1 Spatial Distribution--

The distribution of a pentachlorocylopentane isomer (tentative identification) in the surficial sediments of Hylebos Waterway is shown in Figure 7.2.32. This compound is only one of a number of co-existing chlorinated compounds in Hylebos Waterway sediments. Only a portion of these compounds has been identified. Highest sediment concentrations of the isomer, normalized to dry weight or organic carbon, were found about 4,000 ft from the mouth of the waterway. Concentrations of the pentachlorocyclopentane isomer in the surficial sediments were uniformly low less than 3,000 ft from the mouth and greater than 6,000 ft. The overall pattern of contamination resembled those shown in Figures 7.2.19 through 7.2.23 for chlorinated benzenes and chlorinated butadienes, suggesting that a common source may be involved. No AET was established for this compound.

The vertical pattern of contamination of pentachlorocylopentane could not be determined because sediment core data were not yet available for the compound.

7.2.8.2 Loading Estimates--

No known effort has been made specifically to analyze any discharge to Hylebos Waterway for pentachlorocyclopentane isomers or other cycloalkanes.

7.2.8.3 Source Identification--

The area of greatest sediment contamination by this and other chlorinated substances was immediately off the main outfall of Occidental Chemical Corporation. Although neither pentachlorocylopentane or any other chlorinated cycloalkane is known to occur in the waste stream of Occidental or any

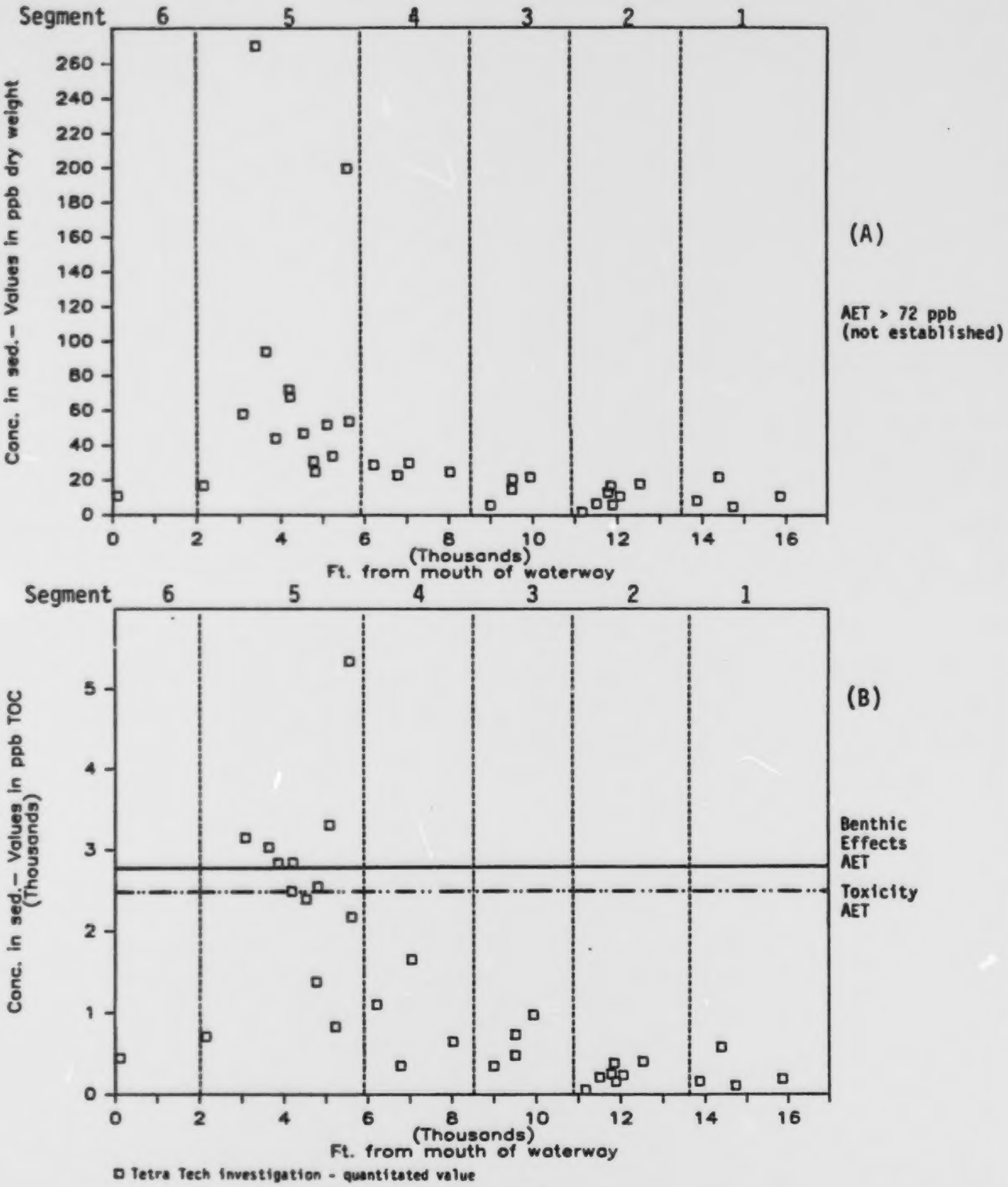


Figure 7.2.32

CONCENTRATIONS OF PENTACHLOROCYCLOPENTANE IN THE SURFICIAL SEDIMENTS OF THE HYLEBOS WATERWAY WITH DISTANCE FROM THE MOUTH OF THE WATERWAY
(A) Concentrations on a dry weight basis
(B) Concentrations normalized to total organic carbon content of the sediments

other firm in the tideflats area, the proximity of the Occidental outfall to the area of contamination suggests strongly that this discharge may be the ultimate source.

Chlorinated cycloalkanes could be in the Occidental waste stream (Payne, J., personal communication). The firm produces chlorine by electrolysis of a sodium chloride brine. Although the firm has partially converted to steel titanium anodes, graphite anodes impregnated with linseed oil have historically been used. During electrolysis, the linseed oil reacts with the free chlorine in the cell, producing a wide variety of chlorinated organic by-products. Chlorinated organic compounds found in the Occidental waste stream include chloroform, carbon tetrachloride, chlorinated ethenes, chlorinated propenes, chlorinated butadienes, chlorinated benzenes, and several unidentified chlorinated organic compounds (Yake 1980; Riley 1981). A cyclic structure, such as pentachlorocyclopentane, could be formed if an alkene undergoes a cycloaddition reaction with another unsaturated molecule (Roberts et al. 1981). This reaction could be favored by electrolysis of the brine. While the existing data are inadequate to establish that pentachlorocylocpentane is formed in the chlorine cells rather than in other production facilities at Occidental (e.g, the old solvent plant), the above scenario does provide a reasonable explanation to serve as a basis for further investigations.

7.2.8.4 Summary and Recommendations--

Since chlorinated cycloalkanes have not typically been contaminants of concern to regulatory agencies, neither the discharge of Occidental Chemical Corporation nor those of any other industry in the tideflats area has been tested for these compounds. Nevertheless, it appears likely that Occidental Chemical Corporation is the major source of the pentachlorocyclopentane isomers and related cycloalkanes to Hylebos Waterway for a number of reasons:

- Concentrations of pentachlorocyclopentane were elevated in the waterway sediments immediately off the main plant outfall.

- The distribution of the contaminant in the sediments was very similar to the distributions of chlorinated benzenes and butadienes (Occidental has been shown to be a major source).

- Pentachlorocylopentane and other cycloalkanes could be formed in the chlorine production cells at Occidental.

If pentachlorocyclopentane is eventually determined to be a problem chemical then:

- Groundwater beneath Occidental Chemical Corporation should be analyzed for the presence of chlorinated cycloalkanes.

- The mass spectra of "unidentified chlorinated organics" reported to be in the Occidental effluent during the Class II survey should be reviewed to determine if chlorinated cyclopentanes are present.

7.2.9 Arsenic

7.2.9.1 Spatial Distribution--

Surficial sediments of Hylebos Waterway contained concentrations of arsenic ranging from approximately 4 to 700 mg/kg (Figure 7.2.33). This range was not constant over the length of the waterway. Arsenic concentrations in surficial sediment were significantly elevated in the upper 6,000 ft (Segments 1, 2 and 3) relative to the remainder of the waterway. This spatial distribution indicates sources located near the head of the waterway. The highest concentrations occurred in Segment 2 at intertidal stations between 11,500 and 13,000 ft from the mouth, and at the upper end of Segment 1 between 16,000 and 16,500 ft from the mouth. This suggests the presence of at least two sources in the waterway. As discussed earlier, data normalized to percent fine-grained material are not presented for arsenic or other inorganic substances. Grain size data are missing for the intertidal samples with the highest concentrations.

The four sediment cores taken in upper Hylebos Waterway, approximately 12,000 to 14,000 ft from the mouth, showed different vertical patterns of arsenic contamination. Arsenic concentrations in the surface horizons of three cores (HY-60, HY-60A, HY-61) were 4 to 20 times greater than those in lower horizons. Concentrations in the surface horizon of core HY-60B were lower than those in lower horizons. The vertical pattern of arsenic contamination suggests that present input of arsenic is generally greater than historical input.

7.2.9.2 Loading Estimates--

There are 22 discharges to Hylebos Waterway with calculated arsenic loadings. Arsenic loadings in surface runoff from six log sorting yards have also been estimated (Norton and Johnson 1985a). Loadings, concentrations, and flows from each of these sources are shown in Table 7.2.7. The greatest quantified loadings of arsenic were attributable to discharges from the Pennwalt Corporation property (14.6 lb/day). Drain HY-056, a presently disconnected surface water runoff outfall, contributed 7.2 lb/day. The Pennwalt main outfall effluent contributed 4.3 lb/day. Other surface water runoff discharges and groundwater seeps at Pennwalt contributed an additional 2.2 lb/day. An additional 0.92 lb/day arsenic is contributed by groundwater beneath the Pennwalt property (not shown in Table 7.2.7; AWARE 1981).

Other discharges contributing over 1 lb/day of arsenic to Hylebos Waterway include the Occidental Chemical Corporation's main outfall (4.7 lb/day), the Wasser Winters log sorting yard (4.4 lb/day), the Louisiana Pacific log sorting yard (4.3 lb/day), Hylebos Creek (2.4 lb/day), and the Murray Pacific log sorting yard No. 1 (1.4 lb/day).

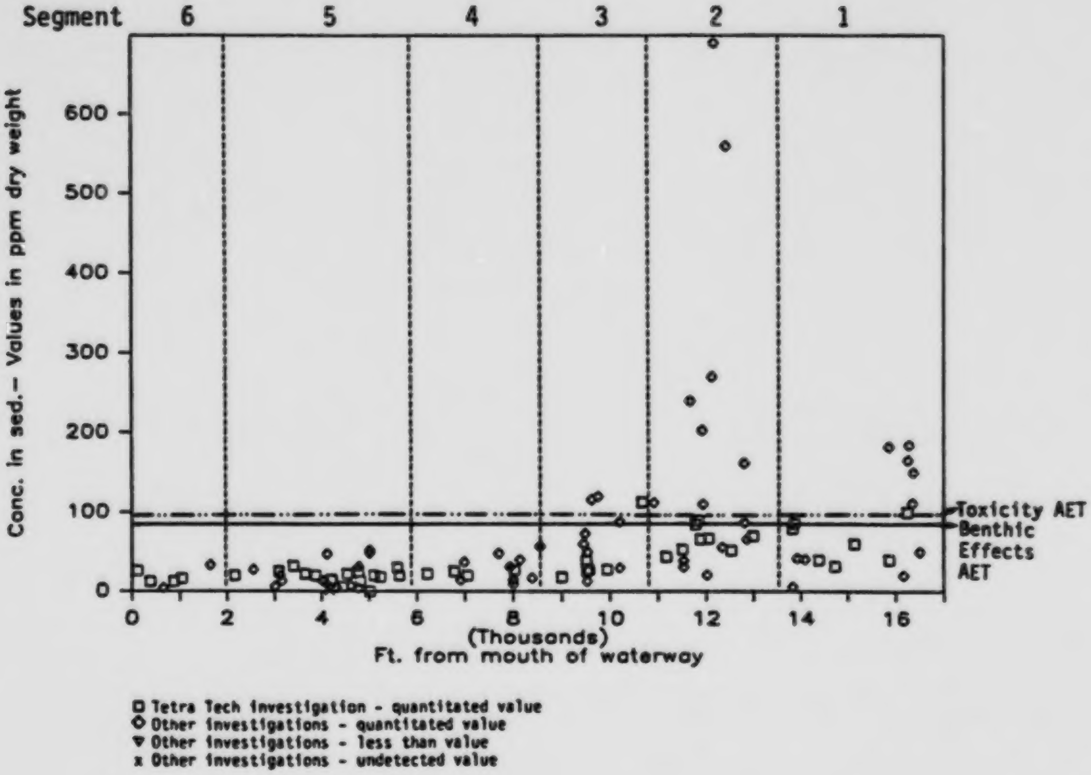


Figure 7.2.33

CONCENTRATIONS OF ARSENIC IN THE SURFICIAL SEDIMENTS OF THE HYLEBOS WATERWAY WITH DISTANCE FROM THE MOUTH OF THE WATERWAY
Concentrations on a dry weight basis

Table 7.2.7

ARSENIC: SUMMARY OF LOADINGS FROM DISCHARGES TO HYLEBOS WATERWAY

Drain #	Drain Name	Flow (MGD) (Avg. and Range) (# of Observations)	Period of Observations for Contaminant Concentrations	Concentration (ug/l) (Avg. and Range) (# of Observations)	Loading (lbs/day) (Avg. and Range)
INDUSTRIAL DISCHARGES					
HK-052	Kaiser Ditch	1.9 (0.23-2.9) (n=8)	6/3/80-4/17/84	41 (4-120) (n=9)	0.65 (0.063-1.90)
HY-058	Pennwalt Main Outfall	11 (9.4-12) (n=2)	6/2/81	Not available	3.9 (net) --- (n=1)
HY-704	Sound Refining Main Effluent	0.053 --- (n=1)	6/3/80	3 --- (n=1)	0.0013 ---
DRAINS AND RUNOFF					
HM-028	Morningside Ditch	0.66 (0.49-0.78) (n=3)	9/23/80-11/7/83	8.1 (2-20) (n=7)	0.0045 (0.0011-0.011)
HY-016	Crack in Bulkhead	0.071 --- (n=1)	9/24/80	71 --- (n=1)	0.042 ---
HY-018	Eight-inch Steel Pipe	0.001 --- (n=1)	6/30/81	15 --- (n=1)	0.00013
HY-021	Thirty-inch Concrete Pipe	0.060 --- (n=1)	4/28/82	12 --- (n=1)	0.0060 ---
HY-023	Storm Drain from hillside NE of Highline Road	0.050 --- (n=1)	4/28/82	89 --- (n=1)	0.037 ---
HY-054	East Channel Ditch	0.0055 (0.0014-0.01) (n=3)	9/23/80-5/17/84	14,740 (110-140,000) (n=6)	0.68 (0.0050-6.4)
HY-055	Eight-inch PVC Pipe	0.0046 --- (n=1)	4/7/81-5/31/83	1,318 (770-1,700) (n=2)	0.051 (0.030-0.065)
HY-056	Six-inch Concrete Pipe (currently disconnected)	0.017 (0.0043-0.029) (n=2)	4/7/81-8/13/81	50,730 1,920-114,000 (n=4)	7.2 (0.27-16.16)
HY-063	Eighteen-inch Steel Pipe	0.11 (0.012-0.39) (n=5)	11/4/83-5/3/84	843 (199-1,756) (n=5)	0.77 (0.18-1.6)

Table7.2.7(cont'd)

HY-065	Six and Eighteen-inch Steel Pipes	0.039 (0.011-0.11) (n=4)	11/4/83-5/3/84	2,431 (950-4,776) (n=5)	0.79 (0.31-1.6)
HY-066	Lincoln Avenue Storm Drain	0.043 (0.029-0.05) (n=3)	4/28/82-5/31/84	21 (1-37) (n=3)	0.00075 (0.00036-0.013)
HY-076	Thirty-inch Concrete Pipe	0.040 --- (n=1)	4/28/82	31 --- (n=1)	0.010 ---
HY-078	Twelve-inch Concrete Pipe	0.025 (0.02-0.03) (n=2)	5/17/84	4 --- (n=1)	0.00083 ---
HY-085	Seven Steel Pipes	0.0007 --- (n=1)	9/23/80	105 --- (n=1)	0.00061
HY-708	Pennwalt East Storm Drain (currently disconnected)	0.0043 --- (n=1)	4/7/81	1,600 --- (n=1)	0.057 ---
HY-709	Pennwalt Sewer Pipe (currently disconnected)	0.0066 (0.0058-0.0074) (n=2)	6/3/80-6/2/81	23,000 (7,500-49,000) (n=3)	1.3 (0.41-2.7)
GROUNDWATER BANK SEEPS					
HY-700	Pennwalt East Seep	0.00079 (0.00036 - 0.0014) (n=3)	6/3/80-4/18/84	113 (36-310) (n=4)	0.00075 (0.000028-0.0020)
HY-701	Pennwalt West Seep	0.0012 (0.001-0.0014) (n=2)	9/23/80-8/13/81	11,935 (5,000-25,300) (n=3)	0.12 (0.050-0.25)
LOG SORT YARDS					
	Wasser Winters	0.13 (0.015-0.32) (n=5)	11/4/83-5/3/84	6,400 (1,400-12,000) (n=5)	4.4 (1.5-10.4)
	Murray Pacific Yard #1	0.20 (0.023-0.73) (n=5)	11/4/83-5/3/84	1,800 (500-3,400) (n=5)	1.4 (0.25-3.1)
	Cascade Timber Yard #1	0.003 --- (n=1)	12/12/83-6/29/84	4,625 (1,970-7,280) (n=2)	0.12 (0.049-0.18)
	Cascade Timber Yard #2	0.035 (0.005-0.065) (n=2)	12/12/83-6/29/84	2,531 (122-4,940) (n=2)	0.74 (0.036-1.4)
	Louisiana Pacific	0.36 (0.06-0.66) (n=2)	12/12/83-6/29/84	1,415 (850-1,980) (n=2)	4.3 (2.6-5.9)

Table7.2.7(cont'd)

	Weyerhaeuser	0.055 (0.024-0.086) (n=2)	1/5/84-6/29/84	38 (32-44) (n=2)	0.018 (0.015-0.020)
	Dunlap Towing	Not available	12/12/83-6/29/84	3,240 (2,680-3,800) (n=2)	---
HYLEBOS CREEK					
HC-000	Hylebos Creek WDOE Station 17	16 (4.9-44) (n=5)	8/22/83-9/5/84	18 (2-67) (n=12)	2.4 (0.27-8.9)

NOTES: Arsenic has been analyzed for, but not detected in the following drains (numbers in parentheses represent numbers of analyses and detection limits): HY-017 (1, 2 ug/l) and HY-077 (1, 16 ug/l).

No net loading of arsenic was reported for HY-707 (Occidental main effluent) in the single set of analyses for which both influent and effluent data are available (Yake 1980).

L = less than

7.2.9.3 Source Identification--

Based on both sediment chemistry and loading data, Pennwalt Corporation, log sorting yards, and Hylebos Creek are presently or have been major sources of arsenic to Hylebos Waterway. These three sources are discussed below.

Pennwalt Corporation--Intertidal sediments along the Pennwalt waterfront had higher arsenic concentrations than any other surficial sediments in Hylebos Waterway. Arsenic loading from discharges associated with the Pennwalt property was approximately three times that from any other source. Therefore, the firm has probably been a source of arsenic to the waterway.

Of the 14.2 lb/day of arsenic attributable to Pennwalt, over half (8.5 lb/day) can be attributed to three drains that are currently disconnected: HY-056, HY-708, and HY-709. Prior to 1981, these drains (and a fourth unnumbered drain) discharged surface water runoff from the eastern portion of the plant property, where sodium arsenite pesticide (Penite) had been produced in the 1940s and 1950s (AWARE 1981; Yake 1982a). Sodium arsenite sludges were landfilled on the property between the chlorine and sodium hydroxide production area and the Taylor Lake waste ponds. AWARE (1981) suggested that arsenic in the effluent from HY-056, HY-708, and HY-709 originated from arsenite sludges remaining in the sewers from the period of Penite production. In 1981, discharge from these drains was discontinued and all surface water runoff was routed to the main plant outfall.

The effect on arsenic loading of diverting surface water runoff is not known, because arsenic analyses of this effluent have not been done since then. Prior to rerouting the runoff from the four eastern drains, analyses of the main outfall effluent performed during the WDOE Class II survey indicated a net loading of 3.9 lb/day arsenic to Hylebos Waterway. The source of the arsenic to the main outfall is unknown. No current process waste stream at Pennwalt is expected to contain arsenic. Any increase in arsenic concentrations in the main outfall effluent above that measured in the influent should originate only from surface water runoff.

Groundwater from beneath the Penite sludge disposal area has been and continues to be a source of arsenic to the waterway. Estimated loadings from groundwater sources are approximately 0.92 lb/day (AWARE 1981). Remedial action such as capping the Penite pond is being discussed with Pennwalt at this time, but the potential improvement of groundwater quality cannot be predicted (Pierce, R., personal communication).

Log Sorting Yards--There are six unpaved or partially paved log sorting yards along Hylebos Waterway. They include Cascade Timber yards No. 1 and 2, Wasser Winters yard, the Louisiana Pacific yard, Murray Pacific yard No. 1, and Dunlap Towing. Together, these yards contribute approximately 11 lb/day of arsenic to Hylebos Waterway via surface water runoff. (No flow data were available from Dunlap Towing to calculate loading.) This arsenic originates ASARCO slag, which was used as ballast at these yards. Available information from Norton and Johnson (1985a) indicates that 1,100 tons of slag have been used as ballast at Dunlap Towing and 29,225 tons have been used at Murray Pacific yard No. 1. Quantities of slag used at other yards have not been documented. ASARCO slag was not used as ballast at the Weyerhaeuser log sorting yard. The Weyerhaeuser yard is the only completely paved yard in the tideflats area and contributes less arsenic than any other log sorting yards. All or part of the other yards are unpaved. Norton and Johnson (1985a) sampled yard runoff, nearshore and offshore sediments, and water near the sorting yards in Hylebos Waterway. The Wasser Winters yard and Murray Pacific yard No. 1 were sampled more intensively than the other five yards because most of their runoff is channeled and thus is more effectively sampled. Arsenic concentrations in runoff from all seven yards varied considerably, ranging from 32 ug/L at Weyerhaeuser (January 5, 1984) to 12,000 ug/L at Wasser Winters (May 3, 1984).

Based on the loading data presented earlier, Wasser Winters, Louisiana Pacific, and Murray Pacific yard No. 1 are the largest contributors of arsenic to the waterway. Arsenic loading from Dunlap Towing was not quantified, but its contribution could be greater than either Murray Pacific yard No. 1 or Louisiana Pacific (Norton and Johnson 1985a). The loadings discussed above and presented in Table 7.2.7 are based on actual measurements of arsenic concentrations and surface water runoff flow provided by Norton and Johnson (1985a). Norton and Johnson also estimated loading based on yard surface area and runoff coefficients. Total estimated average annual daily loading from the six log sorting yards calculated in this manner was 2.3 lb/day. Loading during storm events is probably higher. As noted by Norton and Johnson (1985a), the loadings calculated from runoff coefficients and surface areas are less than those determined by actual measurements, probably because the former technique may substantially underestimate loading during storm events.

Groundwater beneath the log sorting yards represents another potential source of arsenic that has not been quantified. Norton and Johnson (1985a) estimated that 40 percent of rain falling on the log sorting yards would leave the properties as surface water runoff. Therefore, approximately 60 percent of precipitation would enter groundwater, with mobilization of metals as the water migrates through the slag. No data are available to estimate the magnitude of arsenic input to the waterway via this route.

Hylebos Creek--An arsenic loading of 2.4 lb/day has been calculated for Hylebos Creek. The WDOE assessed sources of arsenic to the creek in 1983 and 1984 (Johnson and Norton 1984a). Low-flow and high-flow surveys were conducted to focus on changes in contaminant loadings with changes in surface water runoff conditions. Two major sources of arsenic were investigated: the U.S. Gypsum landfill adjacent to Interstate Highway 5, and the B&L Landfill on the Surprise Lake tributary to Hylebos Creek. The U.S. Gypsum landfill was used for disposal of baghouse dust, recovered from the manufacture of mineral-based insulation. ASARCO slag was used as a raw material for the insulation. The baghouse dust is known to contain 21.7 percent arsenic by weight. Approximately 10,000 - 15,000 yd^3 of solid wastes were dumped in this 2.6-ac landfill between 1971 and 1973 (Dames and Moore 1983). Off-specification mineral fibers and shot material were also placed in this landfill and are potential sources of arsenic, although they contain much less arsenic than does baghouse dust. The landfill has been inactive since 1979. As of December, 1984, all contaminated material had been removed from this landfill by U.S. Gypsum. Thus, release of arsenic from the site to Hylebos Creek can be expected to decrease with time.

B&L Landfill consists primarily of soil and wood wastes from log sorting yards in the Tacoma tideflats. This site is not a permitted landfill, operations have apparently ceased, and potential for enforcement action is being pursued (Hedges, J., personal communication; Pierce, R., personal communication). The WDOE study (Johnson and Norton 1984a) found that leachate from this landfill contained up to 10,000 ug/L total arsenic during January, 1982 and as much as 26,900 ug/L in August, 1983. In summer low-flow periods, leachate from B&L Landfill does not significantly impact arsenic concentrations in Hylebos Creek. However, in winter high-flow periods, discharge from the B&L Landfill is the largest source of arsenic to Hylebos Creek and results in a threefold increase in arsenic concentrations in Hylebos Creek in the vicinity of the discharge (Johnson and Norton 1984a).

7.2.9.4 Summary and Recommendations--

Based on the spatial gradient of arsenic contamination in surficial sediments, the major sources of arsenic to Hylebos Waterway are located in Segments 1 and 2. A number of sources in this area have been identified. However, it is difficult to prioritize these sources with regard to future remedial action, since the success of past remedial actions at Pennwalt and at the US. Gypsum landfill have not been adequately assessed. Four major sources of arsenic to Hylebos Waterway are summarized below in order of ascending mass loading:

- Pennwalt Corporation - The total arsenic loading to Hylebos Waterway from discharges on this property was calculated to be 14.2 lb/day in the early 1980s. Since 1981, the disconnection of several discharges and the rerouting of surface water runoff may have substantially reduced the loading from this facility. The main plant effluent contributes 3.9 lb/day of this total. Since no known process effluents contain arsenic, the origin of the 3.9 lb/day is not known. The only known current source of arsenic is the site where sodium arsenite sludges have been landfilled. This site may also be impacting environmental quality via groundwater (0.9 lb/day arsenic).

- Log Sorting Yards - Total loading of arsenic via surface runoff from the seven log sorting yards surrounding Hylebos Waterway is 11 lb/day (based on sample data). The largest contributors to this loading are Wasser Winters (4.4 lb/day), Louisiana Pacific (4.3 lb/day) and Murray Pacific yard No. 1 (1.4 lb/day). Migration of arsenic from log sorting yards to Hylebos Waterway through groundwater could be significant but cannot be quantified at the present time.

- Hylebos Creek - Arsenic loading to the waterway from Hylebos Creek was estimated at approximately 2.4 lb/day. There are two major sources of arsenic to the creek, both of which result from past landfilling of arsenic-contaminated materials: B&L Landfill (disposal of soil and wood waste from log sorting yards); and the U.S. Gypsum landfill (disposal of arsenic-contaminated baghouse dust). The recent removal of contaminated material from the U.S. Gypsum landfill can be expected to reduce the release of arsenic from this site over time.

The following recommendations may help define sources of arsenic to Hylebos Waterway:

- Investigate and control the unexplained high arsenic concentrations in the Pennwalt main effluent.
- Consider removing Penite wastes on the Pennwalt property to reduce the arsenic quantities reaching Hylebos Waterway via groundwater.
- Consider removing contaminated waste or initiating runoff/leachate controls in order to reduce the migration of arsenic from the B&L Landfill.
- Establish a network of groundwater monitoring wells in order to quantify the amount of arsenic reaching Hylebos Waterway via groundwater from the log sorting yards.
- Initiate runoff control measures at the log sorting yards.

Current discharges of arsenic to Hylebos Waterway could be dramatically curtailed by the source control measures identified above. The three sources identified (Pennwalt, log sorting yards, Hylebos Creek) contribute 92 percent of the quantified arsenic loading. A substantial reduction in arsenic concentrations in these sources can be expected to result in a measurable improvement in sediment quality over time.

7.2.10 Copper, Lead and Zinc

7.2.10.1 Spatial Distribution--

Copper, lead, and zinc have been designated as preliminary contaminants of concern in Hylebos Segment 1. Distributions of the contaminants in the surficial sediments of Hylebos Waterway are shown in Figures 7.2.34 - 7.2.36. For copper and zinc, concentrations decreased from the head to the mouth of the waterway. Concentration (dry weight) of both metals in Hylebos Segment 6 at the mouth of the waterway are approximately one-fourth of those in Segment 1 at the head of the waterway. There is also some evidence of decreasing lead concentration from the head to the mouth of the waterway, although the gradient is not as apparent as those for copper

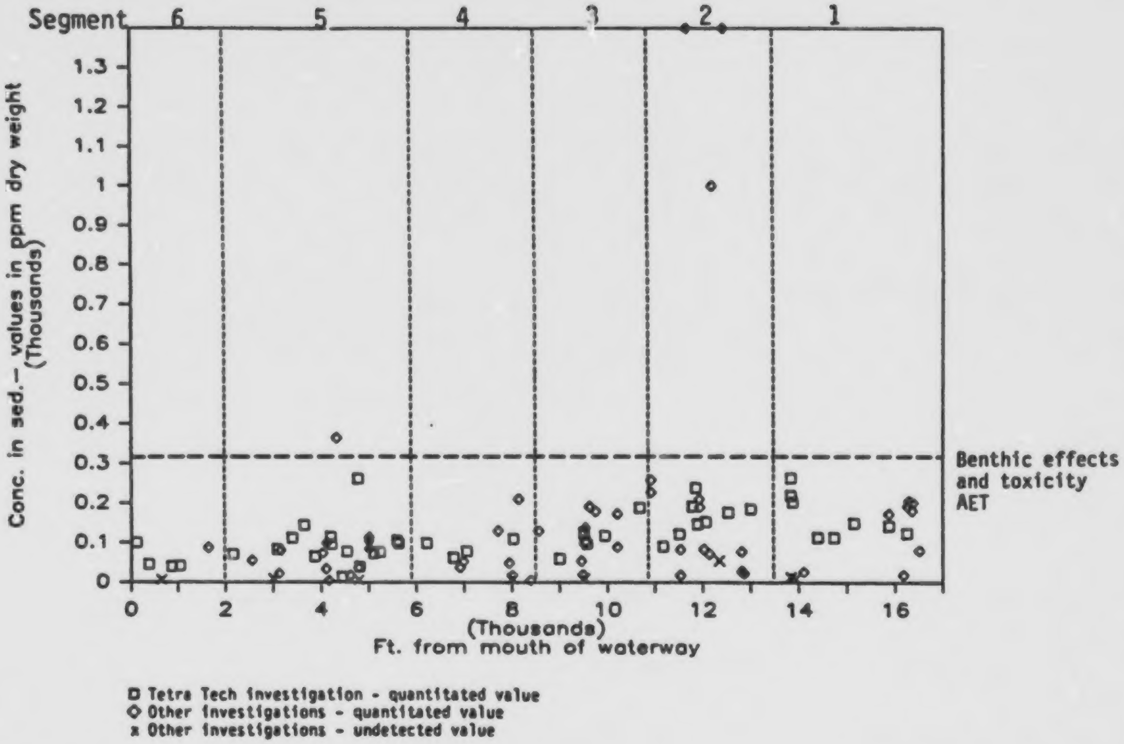


Figure 7.2.34

CONCENTRATIONS OF COPPER IN THE SURFICIAL SEDIMENTS OF THE HYLEBOS WATERWAY WITH DISTANCE FROM THE MOUTH OF THE WATERWAY
Concentrations on a dry weight basis

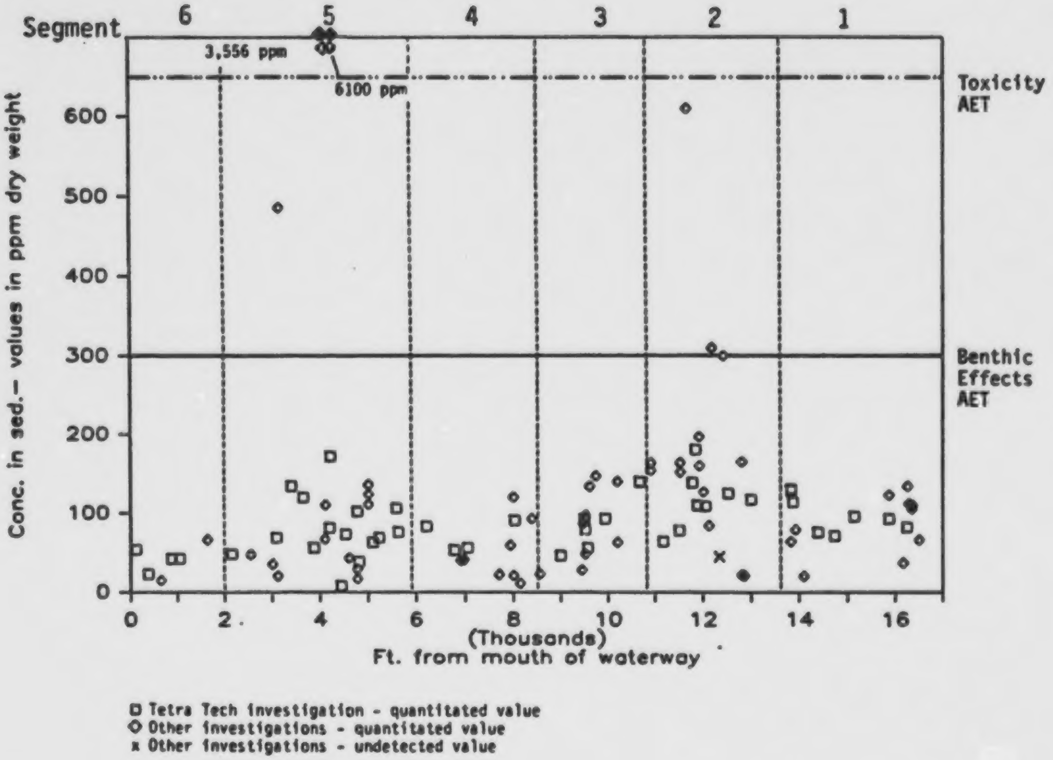


Figure 7.2.35

CONCENTRATIONS OF LEAD IN THE SURFICIAL SEDIMENTS OF THE HYLEBOS WATERWAY WITH DISTANCE FROM THE MOUTH OF THE WATERWAY
Concentrations on a dry weight basis

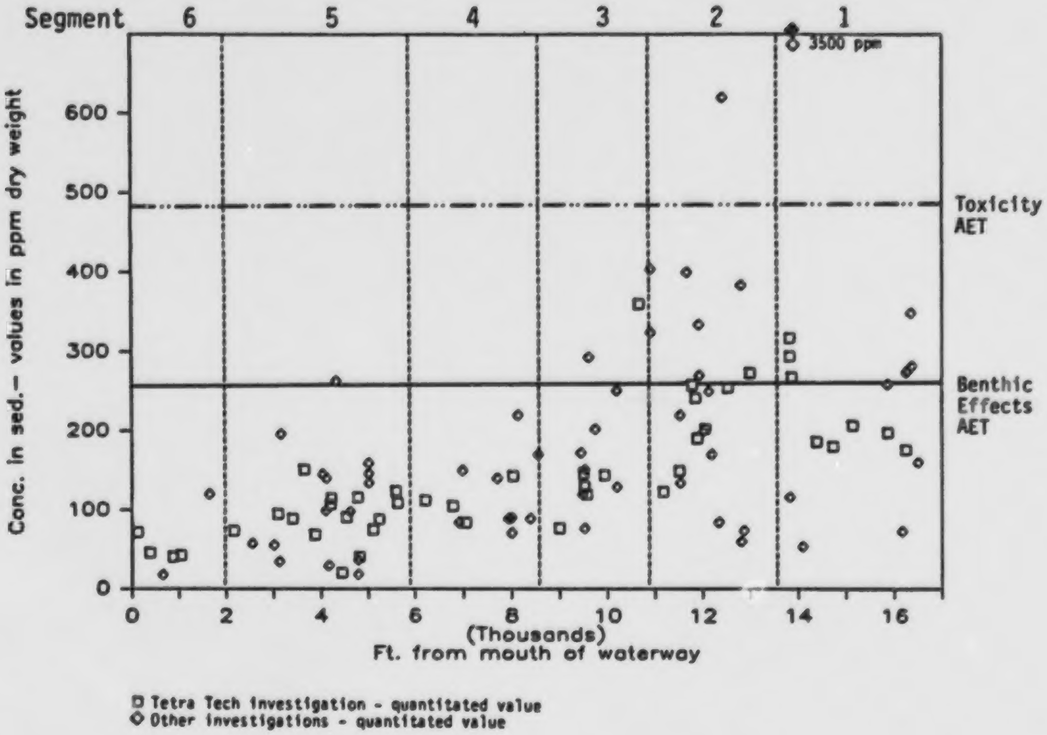


Figure 7.2.36

CONCENTRATIONS OF ZINC IN THE SURFICIAL SEDIMENTS OF THE HYLEBOS WATERWAY WITH DISTANCE FROM THE MOUTH OF THE WATERWAY
Concentrations on a dry weight basis

and zinc. Nickel is a priority contaminant in Segments 2 and 5. Although source evaluations were not conducted for nickel, it has a similar distribution to the other metals discussed in this section (Figure 7.2.37).

Superimposed upon the gradients along the length of the waterway are two areas of elevated concentrations associated with nearby sources. Increased metal concentrations were apparent in intertidal stations located at 12,000 and 4,000 ft from the waterway mouth. Concentrations of all three metals were elevated at one or more intertidal stations at 12,000 ft from the mouth of the waterway. At 4,000 ft from the mouth, lead concentrations (dry weight) in intertidal sediments were up to three orders of magnitude greater than those in sediments from nearby stations in the central waterway. Except for lead, metal concentrations were not significantly elevated at these stations when normalized to dry weight. Sediments at these stations were extremely coarse (0.5-1.2 percent fines) and concentrations were high when normalized to percent fine-grained material.

The intertidal stations at 4,000 and 12,000 ft from the waterway that had elevated concentrations of one or more of the metals were located along the southern shoreline, indicating the presence of metal sources along this shore. Beyond this, there were no cross-waterway gradients of contamination to help establish locations of other sources.

Sediment core samples taken about 12,000 and 14,000 ft from the mouth of the waterway showed the same distribution of metals with depth in the sediments (Figure 7.2.38). Concentrations of all metals were 3 to 10 times greater in the upper horizon than they were in subsurface horizons. This indicates the copper, lead, and zinc input to Hylebos Waterway above 12,000 ft from the mouth is substantially greater at present than it was in the past.

7.2.10.2 Loading Estimates--

Data available for copper, lead and zinc loading to the Hylebos Waterway are shown in Tables 7.2.8, 7.2.9, and 7.2.10.

On the basis of these data, the major sources of copper to Hylebos Waterway were the Pennwalt main outfall (2.4 lb/day); Hylebos Creek (2.4 lb/day); the Cascade Timber yard No. 2, Wasser Winters, and Louisiana Pacific log sorting yards (1.2, 1.0 and 0.73 lb/day, respectively); and Kaiser Ditch (0.43 lb/day). The greatest sources of lead were Hylebos Creek (1.1 lb/day), Cascade Timber yard No. 2 (0.72 lb/day), Wasser Winters (0.62 lb/day), Kaiser Ditch (0.51 lb/day), and Louisiana Pacific (0.49 lb/day). The greatest sources of zinc were Hylebos Creek (6.5 lb/day), Kaiser Ditch (1.8 lb/day), Cascade Timber yard No. 2 (1.6 lb/day), Wasser Winters (1.5 lb/day), and Murray Pacific yard No. 1 (1.5 lb/day). It should be noted that no flow data were available for Dunlap Towing, although the facility could be as significant a source of metals as the other log sorting yards listed (Norton and Johnson 1985a).

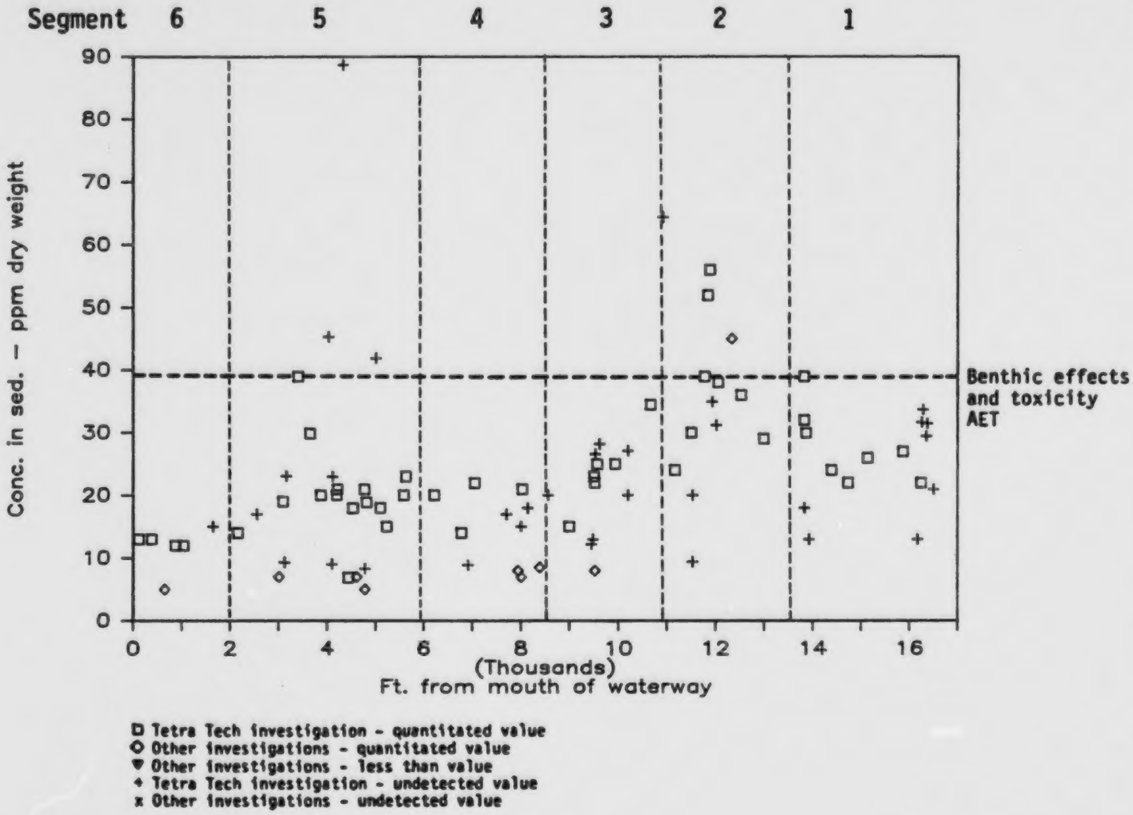


Figure 7.2.37

CONCENTRATIONS OF NICKEL IN THE SURFICIAL SEDIMENTS OF THE HYLEBOS WATERWAY WITH DISTANCE FROM THE MOUTH OF THE WATERWAY

Concentrations on a dry weight basis

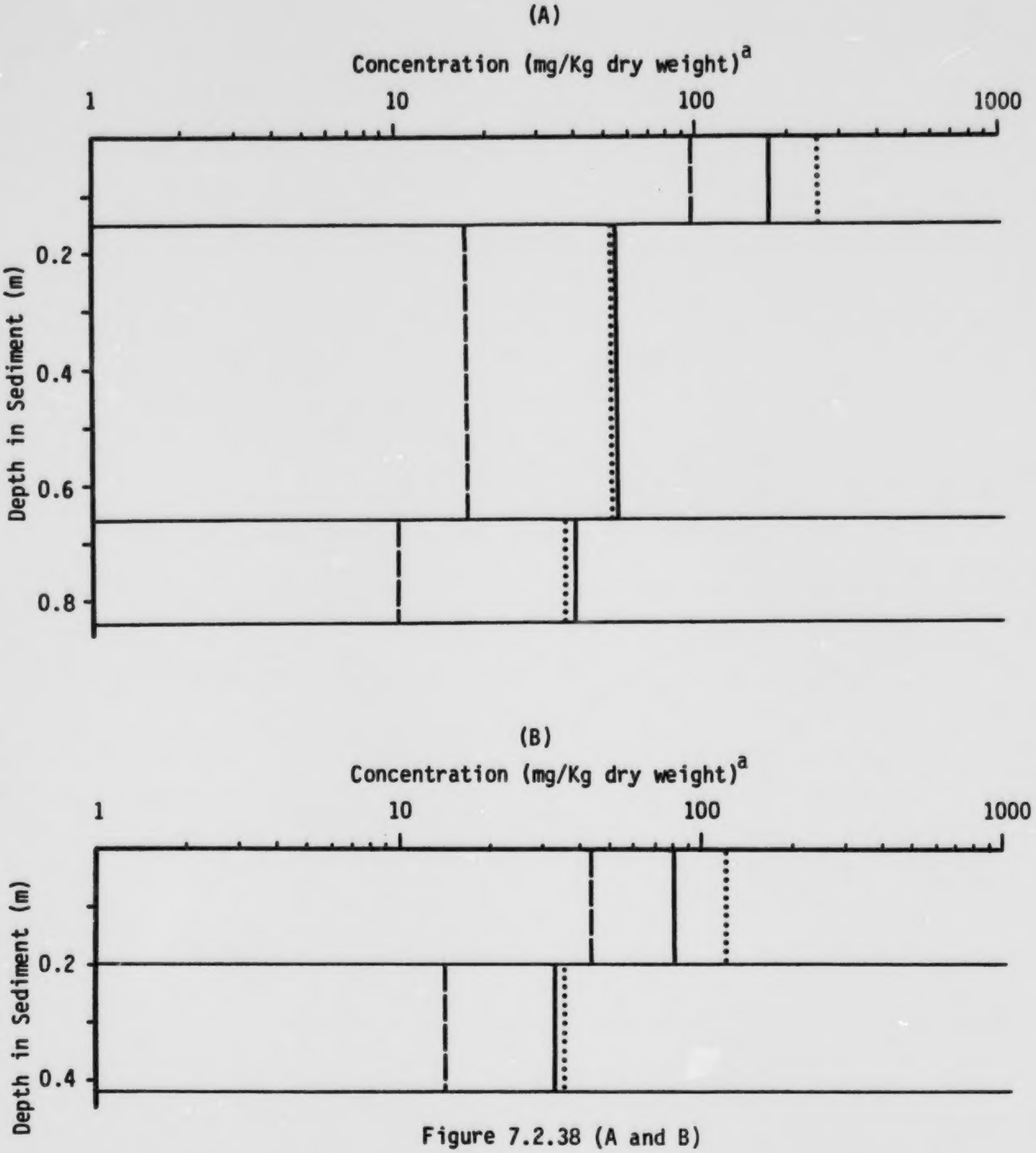


Figure 7.2.38 (A and B)

CONCENTRATIONS OF METALS WITH DEPTH IN THE SEDIMENT COLUMN:
(A) STATION HY-60, G01, (B) STATION HY-60A, B01

——— Copper
- - - - - Lead
· · · · · Zinc

[a] No AET are exceeded for these metals in the cores shown (see Table 4.1 for AET values).

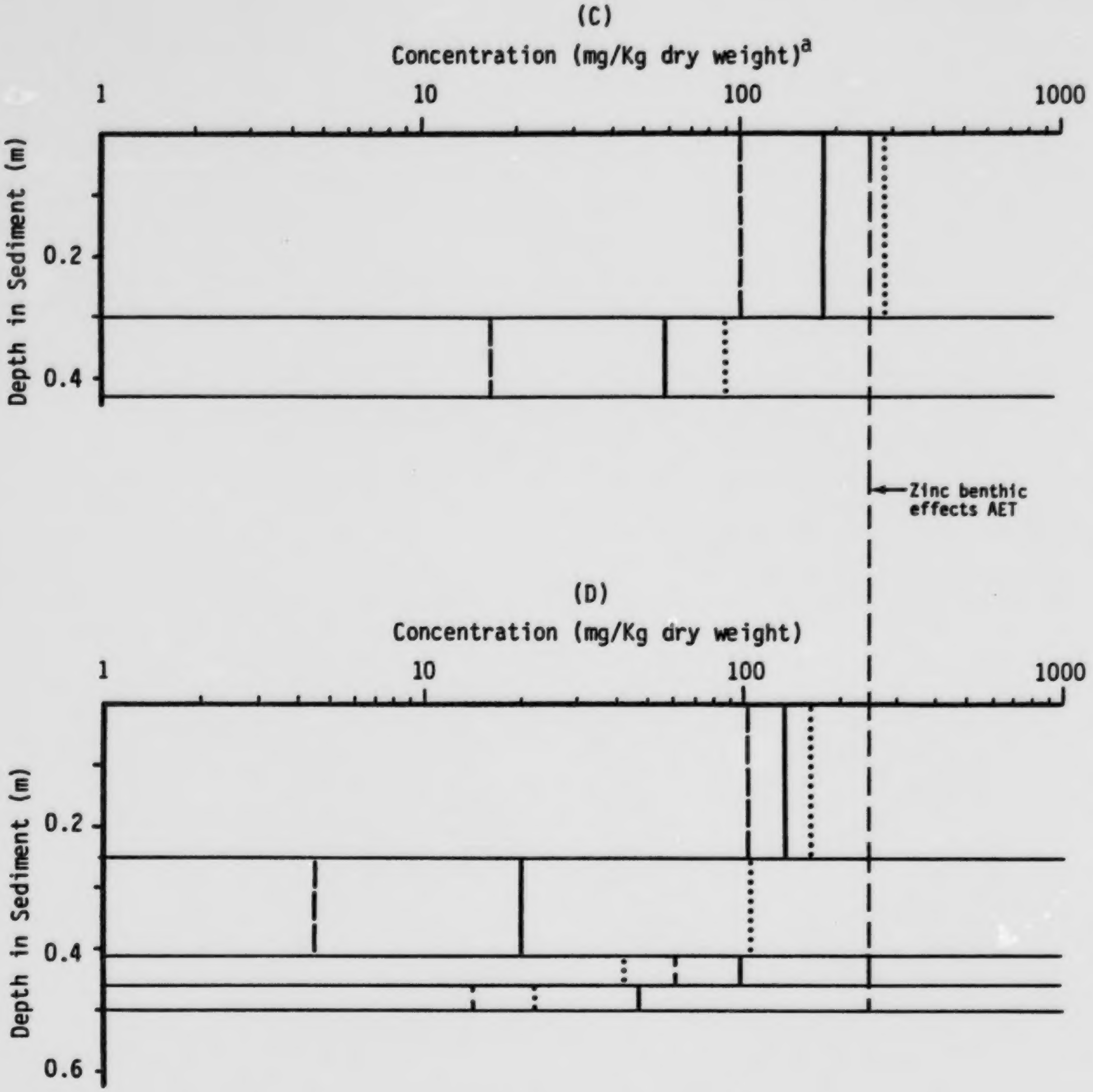


Figure 7.2.38 (C and D)

CONCENTRATIONS OF METALS WITH DEPTH IN THE SEDIMENT COLUMN:
(C) STATION HY-60B, B02; (D)STATION HY-61, B02

——— Copper
- - - - - Lead
· · · · · Zinc

[a] Of the metals shown, only Zinc concentrations exceed an AET in these areas (see Table 4.1 for AET values).

Table 7.2.8

COPPER: SUMMARY OF LOADINGS FROM DISCHARGES TO HYLEBOS WATERWAY

Drain #	Drain Name	Flow (MGD) (Avg. and Range) (# of Observations)	Period of Observations for Contaminant Concentrations	Concentration (ug/l) (Avg. and Range) (# of Observations)	Loading (lbs/day) (Avg. and Range)
INDUSTRIAL DISCHARGES					
HK-052	Kaiser Ditch	1.9 (0.23-2.9) (n=8)	6/3/80-11/7/83	27 (15-64) (n=5)	0.43 (0.24-1.01)
HY-058	Pennwalt Main Outfall	11 (9.4-12) (n=2)	5/22/79-6/2/81	Not available	2.4 (net) (1.5-3.3) (n=2)
HY-704	Sound Refining Main Effluent	0.053 --- (n=1)	6/3/80-6/30/81	13 (3-16) (n=2)	0.0057 (0.0013-0.00071)
DRAINS AND RUNOFF					
HM-028	Morningside Ditch	0.66 (0.49-0.78) (n=3)	9/23/80-11/7/83	20 (10-41) (n=4)	0.11 (0.055-0.23)
HY-016	Crack in Bulkhead	0.071 --- (n=1)	9/24/80-6/30/81	21 (14-27) (n=2)	0.012 (0.0083-0.016)
HY-018	Eight-inch Steel Pipe	0.001 --- (n=1)	6/30/81	10 --- (n=1)	0.000083 ---
HY-054	East Channel Ditch	0.0055 (0.0014-0.01) (n=3)	9/23/80-5/17/84	9,037 (18-90,000) (n=5)	0.41 (0.00083-4.1)
HY-055	Eight-inch PVC Pipe	0.0046 --- (n=1)	4/7/81	23 --- (n=1)	0.00088 ---
HY-056	Six-inch Concrete Pipe (currently disconnected)	0.017 (0.0043-0.029) (n=2)	6/3/80-6/2/81	131 (3-363) (n=3)	0.019 (0.00043-0.051)
HY-063	Eighteen-inch Steel Pipe	0.11 (0.012-0.39) (n=5)	11/4/83-5/3/84	75 (31-170) (n=5)	0.069 (0.028-0.16)
HY-065	Six and Eighteen-inch Steel Pipes	0.039 (0.011-0.11) (n=4)	11/4/83-5/3/84	367 (224-668) (n=5)	0.12 (0.073-0.22)
HY-066	Lincoln Avenue Storm Drain	0.043 (0.029-0.05) (n=3)	5/17/84-5/31/84	19 (9-28) (n=2)	0.0068 (0.0032-0.010)

Table7.2.8(cont'd)

HY-076	Thirty-inch Concrete Pipe	0.040 --- (n=1)	4/28/82	20 --- (n=1)	0.0067 ---
HY-078	Twelve-inch Concrete Pipe	0.025 (0.02-0.03) (n=2)	5/17/84-5/31/84	22 (20-25) (n=2)	0.0046 (0.0042-0.0052)
HY-083	Two Seeps at Occidental	0.0051 (0.0002-0.01) (n=2)	4/18/84	281 (76-480) (n=2)	0.012 (0.0032-0.020)
HY-085	Seven Steel Pipes	0.0007 --- (n=1)	9/23/80-4/18/84	384 (234-533) (n=2)	0.0022 (0.0014-0.0031)
HY-708	Pennwalt East Storm Drain (currently disconnected)	0.0043 --- (n=1)	4/7/81	16 --- (n=1)	0.00057 ---
HY-709	Pennwalt Sewer Pipe (currently disconnected)	0.0066 (0.0058-0.0074) (n=2)	6/3/80-6/2/81	26 (15-50) (n=3)	0.0014 (0.00083-0.0028)
GROUNDWATER BANK SEEPS					
HY-700	Pennwalt East Seep	0.00079 (0.00036-0.0014) (n=3)	6/3/80-4/18/84	83 (11-160) (n=4)	0.000547 (0.000072-0.0011)
HY-701	Pennwalt West Seep	0.0012 (0.001-0.0014) (n=2)	9/23/80-6/2/81	53 (31-75) (n=2)	0.00053 (0.00031-0.00075)
LOG SORT YARDS					
	Wasser Winters	0.13 (0.015-0.32) (n=5)	11/4/83-5/3/84	1,200 (160-2,800) (n=5)	1.0 (0.15-3.5)
	Murray Pacific Yard #1	0.20 (0.023-0.73) (n=5)	11/4/83-5/3/84	210 (84-410) (n=5)	0.20 (0.03-0.51)
	Cascade Timber Yard #1	0.003 --- (n=1)	12/12/83-6/29/84	422 (148-695) (n=2)	0.011 (0.0037-0.017)
	Cascade Timber Yard #2	0.035 (0.005-0.065) (n=2)	6/29/84	4,000 --- (n=1)	1.2 ---
	Louisiana Pacific	0.36 (0.06-0.66) (n=2)	12/12/83-6/29/84	242 (73-410) (n=2)	0.73 (0.21-1.2)
	Weyerhaeuser	0.055 (0.024-0.086) (n=2)	6/29/84	121 --- (n=1)	0.056

Table 7.2.8 (cont'd)

	Dunlap Towing	Not available	12/12/83-6/29/84	263 (183-342) (n=2)	---
HYLEBOS CREEK					
HC-000	Hylebos Creek WDOE Station 17	16 (4.9-44) (n=5)	8/22/83-9/5/84	18 (1-48) (n=9)	2.4 (0.13-6.4)

NOTE: Copper has been analyzed for, but not detected in the following drains (the numbers in parentheses represent number of analyses and detection limits): HY-021 (1, 10 ug/l), HY-023 (1, 10 ug/l).

Table 7.2.9

LEAD: SUMMARY OF LOADINGS FROM DISCHARGES TO HYLEBOS WATERWAY

Drain #	Drain Name	Flow (MGD) (Avg. and Range) (# of Observations)	Period of Observations for Contaminant Concentrations	Concentration (ug/l) (Avg. and Range) (# of Observations)	Loading (lbs/day) (Avg. and Range)
INDUSTRIAL DISCHARGES					
HK-052	Kaiser Ditch	1.9 (0.23-2.9) (n=8)	6/3/80-4/17/84	32 (5-127) (n=9)	0.51 (0.079-2.0)
HY-058	Pennwalt Main Outfall	11 (9.4-12) (n=2)	5/22/79-6/2/81	Not available	0.16 (net) (0.12-0.19) (n=2)
HY-704	Sound Refining Main Effluent	0.053 --- (n=1)	6/3/80, 6/30/81	19 (17-21) (n=2)	0.0084 (0.0075-0.0093)
HY-707	Occidental Main Effluent	15.49 --- (n=1)	9/25/79-10/24/79	Not available	L0.39 (net) --- (n=1)
DRAINS AND RUNOFF					
HM-028	Morningside Ditch	0.66 (0.49-0.78) (n=3)	9/23/80-11/7/83	25 (12-73) (n=6)	0.14 (0.0066-0.40)
HY-016	Crack in Bulkhead	0.071 --- (n=1)	9/24/80	10 --- (n=1)	0.0059 ---
HY-018	Eight-inch Steel Pipe	0.001 --- (n=1)	6/30/81	2 --- (n=1)	0.000017 ---
HY-054	East Channel Ditch	0.0055 (0.0014-0.01) (n=3)	9/23/80-5/17/84	6,782 (5-81,000) (n=6)	0.31 (0.00023-3.7)
HY-055	Eight-inch PVC Pipe	0.0046 --- (n=1)	4/7/81-5/31/83	16 (5-27) (n=2)	0.00061 (0.00019-0.0010)
HY-056	Six-inch Concrete Pipe (currently disconnected)	0.017 (0.0043-0.029) (n=2)	6/3/80-4/7/81	85 (13-157) (n=2)	0.012 (0.0018-0.022)
HY-063	Eighteen-inch Steel Pipe	0.11 (0.012-0.39) (n=5)	2/29/83-5/3/84	49 (1-97) (n=4)	0.045 (0.00092-0.089)
HY-065	Six and Eighteen-inch Steel Pipes	0.039 (0.011-0.11) (n=4)	11/4/83-5/3/84	377 (164-547) (n=5)	0.12 (0.053-0.18)

Table 7.2.9 (cont'd)

HY-066	Lincoln Avenue Storm Drain	0.043 (0.029-0.05) (n=3)	5/17/84-5/31/84	18 (15-20) (n=2)	0.0065 (0.0054-0.0072)
HY-078	Twelve-inch Concrete Pipe	0.025 (0.02-0.03) (n=2)	5/17/84-5/31/84	17 (3-30) (n=2)	0.0035 (0.00063-0.0063)
HY-083	Two Seeps at Occidental	0.0051 (0.0002-0.01) (n=2)	4/18/84	169 (30-306) (n=2)	0.0072 (0.0013-0.013)
HY-085	Seven Steel Pipes	0.0007 --- (n=1)	9/23/80-4/18/84	462 (293-630) (n=2)	0.0027 (0.0017-0.0037)
HY-708	Pennwalt East Storm Drain (currently disconnected)	0.0043 --- (n=1)	4/7/81	20 --- (n=1)	0.00072 ---
HY-709	Pennwalt Sewer Pipe (currently disconnected)	0.0066 (0.0058-0.0074) (n=2)	6/3/80	12 --- (n=1)	0.00066 ---
GROUNDWATER BANK SEEPS					
HY-700	Pennwalt East Seep	0.00079 (0.00036-0.0014) (n=3)	6/3/80-4/18/84	49 (35-79) (n=4)	0.00032 (0.00023-0.00052)
HY-701	Pennwalt West Seep	0.0012 (0.001-0.0014) (n=2)	9/23/80-6/2/81	96 (87-105) (n=2)	0.00096 (0.00087-0.0011)
LOG SORT YARDS					
	Wasser Winters	0.13 (0.015-0.32) (n=5)	11/4/83-5/3/84	700 (130-1,600) (n=5)	0.62 (0.10-2.0)
	Murray Pacific Yard #1	0.20 (0.023-0.73) (n=5)	12/29/83-5/3/84	250 (67-350) (n=4)	0.19 (0.051-0.41)
	Cascade Timber Yard #1	0.003[a] --- (n=1)	12/12/83-6/29/84	373 (36-710) (n=2)	0.0092 (0.00090-0.018)
	Cascade Timber Yard #2	0.035[a] (0.005-0.065) (n=2)	6/29/84	2,470 --- (n=1)	0.72 ---
	Louisiana Pacific	0.36 (0.06-0.66) (n=2)	12/12/83, 6/29/84	164 (17-310) (n=2)	0.49 (0.051-0.93)
	Weyerhaeuser	0.055 (0.024-0.086) (n=2)	6/29/84	35 --- (n=1)	0.016 ---

Table7.2.9 (cont'd)

	Dunlap Towing	Not available	12/12/83-6/29/84	219 (171-267) (n=2)	---
HYLEBOS CREEK					
HC-000	Hylebos Creek WDOE Station 17	16 (4.9-44) (n=5)	8/22/83-9/5/84	80 (1-12) (n=9)	1.1 (0.13-1.6)

NOTE: Lead has been analyzed for but not detected in the following drains (numbers in parentheses represent numbers of analyses and detection limits): HY-076 (1, 20 ug/l), HY-077 (1, 1 ug/l), HY-021 (1, 20 ug/l), HY-023 (1, 20 ug/l).

[a] Flow of individual discharge only; total yard flow not determined.

Table 7.2.10

ZINC: SUMMARY OF LOADINGS FROM DISCHARGES TO HYLEBOS WATERWAY

Drain #	Drain Name	Flow (MGD) (Avg. and Range) (# of Observations)	Period of Observations for Contaminant Concentrations	Concentration (ug/l) (Avg. and Range) (# of Observations)	Loading (lbs/day) (Avg. and Range)
INDUSTRIAL DISCHARGES					
HK-052	Kaiser Ditch	1.9 (0.23-2.9) (n=8)	6/3/80-4/17/84	112 (8-719) (n=9)	1.8 (0.13-11)
HY-058	Pennwalt Main Outfall	11 (9.4-12) (n=2)	6/2/81	Not available	0.4 (net) --- (n=1)
HY-704	Sound Refining Main Effluent	0.053 --- (n=1)	6/3/80-6/30/81	73 (35-90) (n=2)	0.032 (0.015-0.040)
HY-707	Occidental Main Effluent	15.49 --- (n=1)	9/25/79	Not available	0.25 (net) --- (n=1)
DRAINS AND RUNOFF					
HM-028	Morningside Ditch	0.66 (0.49-0.78) (n=3)	9/23/80-11/7/83	176 (51-450) (n=5)	0.97 (0.28-2.5)
HY-016	Crack in Bulkhead	0.071 --- (n=1)	9/23/80-11/7/83	L20 --- (n=1)	L0.012 ---
HY-017	Twelve-inch Corrugated Steel Pipe	0.0039	6/30/81	67 --- (n=1)	0.0022 ---
HY-018	Eight-inch Steel Pipe	0.001 --- (n=1)	6/30/81	170 --- (n=1)	0.0014 ---
HY-021	Thirty-inch Concrete Pipe	0.06 --- (n=1)	4/28/82	10 --- (n=1)	0.0050 ---
HY-054	East Channel Ditch	0.0055 (0.0014-0.01) (n=3)	9/23/80-5/17/84	12,108 (5-120,000) (n=5)	0.56 (0.000092-5.5)
HY-055	Eight-inch PVC Pipe	0.0046 --- (n=1)	4/7/81	52 --- (n=1)	0.0020 ---
HY-056	Six-inch Concrete Pipe (currently disconnected)	0.017 (0.0043-0.029) (n=2)	6/3/80-4/7/81	40 (20-60) (n=2)	0.0057 (0.0028-0.0085)

Table7.2.10(cont'd)

HY-063	Eighteen-inch Steel Pipe	0.11 (0.012-0.39) (n=5)	11/4/83-5/3/84	433 (136-960) (n=5)	0.40 (0.12-1.88)
HY-065	Six and Eighteen-inch Steel Pipes	0.039 (0.011-0.11) (n=4)	11/4/83-5/3/84	2,547 (946-4,630) (n=5)	0.83 (0.31-1.5)
HY-066	Lincoln Avenue Storm Drain	0.043 (0.029-0.05) (n=3)	4/28/82-5/31/84	79 (16-127) (n=3)	0.028 (0.0057-0.046)
HY-076	Thirty-inch Concrete Pipe	0.040 --- (n=1)	4/28/82	72 --- (n=1)	0.024 ---
HY-078	Twelve-inch Concrete Pipe	0.025 (0.02-0.03) (n=2)	5/17/84	35 --- (n=1)	0.0073 ---
HY-083	Two Seeps at Occidental	0.0051 (0.0002-0.01) (n=2)	4/18/84	129 (7-243) (n=2)	0.0055 (0.00030-0.010)
HY-085	Seven Steel Pipes	0.0007 --- (n=1)	9/23/80-4/18/84	920 (289-1,550) (n=2)	0.0054 (0.0017-0.0090)
HY-708	Pennwalt East Storm Drain (currently disconnected)	0.0043 --- (n=1)	4/7/81	615 --- (n=1)	0.022 ---
HY-709	Pennwalt Sewer Pipe (currently disconnected)	0.0066 (0.0058-0.0074) (n=2)	6/3/80-6/2/81	35 (20-60) (n=3)	0.0019 (0.0011-0.0033)
GROUNDWATER BANK SEEPS					
HY-700	Pennwalt East Seep	0.00079 (0.00036-0.0014) (n=3)	6/3/80-4/18/84	106 (2-490) (n=5)	0.00070 (0.000013-0.0032)
HY-701	Pennwalt West Seep	0.0012 (0.001-0.0014) (n=2)	9/23/80-6/2/81	240 (80-400) (n=2)	0.0024 (0.00080-0.0040)
LOG SORT YARDS					
	Wasser Winters	0.13 (0.015-0.32) (n=5)	11/4/83-5/3/84	1,800 (490-3,200) (n=5)	1.5 (0.21-4.0)
	Murray Pacific Yard #1	0.20 (0.023-0.73) (n=5)	11/4/83-5/3/84	1,800 (500-3,400) (n=5)	1.5 (0.23-3.7)
	Cascade Timber Yard #1	0.003 --- (n=1)	12/12/83-6/29/84	2,343 (1,685-3,000) (n=2)	0.059 (0.042-0.075)

Table7.2.10(cont'd)

	Cascade Timber Yard #2	0.035 (0.005-0.065) (n=2)	6/29/84	5,340 --- (n=1)	1.6 ---
	Louisiana Pacific	0.36 (0.06-0.66) (n=2)	12/12/83-6/29/84	335 (170-500) (n=2)	1.0 (0.51-1.5)
	Weyerhaeuser	0.055 (0.024-0.086) (n=2)	1/5/84-6/29/84	445 (240-650) (n=2)	0.2 (0.11-0.3)
	Dunlap Towing	Not available	12/12/83-6/29/84	870 (315-1,425) (n=2)	---
HYLEBOS CREEK					
HC-000	Hylebos Creek WDOE Station 17	16 (4.9-44) (n=15)	8/22/83-9/5/84	49 (1-273) (n=13)	6.5 (0.13-36.4)

Loading estimates indicate that Hylebos Creek is the largest source of copper, lead, and zinc to Hylebos Waterway. This source is discussed further in Section 7.2.9.3.

The log sorting yards represent a significant source of copper, lead, and zinc to the waterway and is further explored below. The Kaiser Ditch represents another source. This ditch drains not only the Kaiser property, but also Cascade Timber yard No. 2, Weyerhaeuser, and Dunlap Towing log sorting yards. The log sorting yards probably contribute a significant portion of the total loading of metals from the ditch. It should be noted that the loading values shown herein for the log sorting yards are based on actual measurements of flow and concentration from the individual yards during storm events, rather than on the average annual daily loading values estimated by Norton and Johnson (1985a) using runoff coefficients and yard area.

While there are no NPDES-permitted discharges of copper or zinc to Hylebos Waterway, there are two permitted discharges of lead. Pennwalt Chemical Corporation has an NPDES permit to discharge an average of 1.0 lb/day (2.0 lb/day maximum). The most recent loading estimate available in the project database (Yake 1982a) indicated an average net loading of 0.16 lb/day of lead to the waterway. Available Discharge Monitoring Report (DMR) data indicate that in 1983-1984, Pennwalt Corporation had an average net loading of approximately 0.6 lb/day lead. Occidental Chemical Corporation is permitted under the NPDES program to discharge a net average of 2.1 lb/day lead (4.3 lb/day maximum) to Hylebos Waterway. DMR data for 1983-1984 indicate that Occidental had an average net lead loading of 1.7 lb/day.

7.2.10.3 Source Identification--

Sources of copper, lead, and zinc to upper Hylebos Waterway include permitted process effluents, surface water runoff, and groundwater seepage. Based on surficial sediment chemistry and loading data, major sources of metals include Hylebos Creek, the log sorting yards, and the Pennwalt Corporation main effluent. Based on the elevated lead concentrations in intertidal sediments at 4,000 ft from the waterway mouth, Occidental Chemical Corporation is also a past and/or present source of lead to Hylebos Waterway. However, it is not a source of lead to the head of the waterway where the contaminant has been designated to be of concern.

Hylebos Creek--Hylebos Creek can be implicated as a major source of metals on the basis of the gradient of decreasing metal concentrations in surficial sediments from the head to the mouth of Hylebos Waterway. Loading data also indicate it is a major source. Hylebos Creek had higher quantified loadings of lead (1.1 lb/day) and zinc (6.5 lb/day) than any other discharge to Hylebos Waterway. Hylebos Creek and the Pennwalt Corporation main outfall had the highest loadings of copper (both 2.4 lb/day).

The data of Johnson and Norton (1985a) indicate that a major source of metals to Hylebos Creek drainage is the Fife ditch system, entering the creek about Marine View Drive (1,400 ft upstream from the mouth of the creek). Flows from this discharge ranged from 0.08 to 10.0 MGD during WDOE's study (Johnson and Norton 1985a). Copper concentrations were 36 ug/L, lead concentrations were 14 ug/L, and zinc concentrations were 18-54 ug/L. Particularly in wet weather, this storm drainage system could represent a significant loading. Zinc loading from Fife Ditch to Hylebos Creek during wet weather was estimated to be 4.7 lb/day (copper and lead data unavailable). The source of metals to this discharge is unknown and requires further investigation.

Two additional potential sources of metals to Hylebos Creek have been identified and investigated by WDOE (Johnson and Norton 1985a): U.S. Gypsum landfill and B&L landfill. The U.S. Gypsum Landfill was used to dump baghouse dust from the manufacture of insulation made with ASARCO slag. This dust contains 6.35 percent lead, 2.83 percent zinc, and 1.03 percent copper by weight. The data of Johnson and Norton (1985a) indicate that U.S. Gypsum is not a major source of copper, zinc, or lead to Hylebos Creek. U.S. Gypsum completed excavation and removal of the contaminated portions of the landfill in December, 1984. Sampling is underway to identify areas of residual contamination and to determine loading to the Hylebos drainage. Results were not available at the time of this writing. As a result of the removal of material from this landfill, input of metals from this source should decrease still further with time.

The B&L Landfill, about 17 ac in size, has received soil and wood waste from log sorting yards since about 1975. This site has never been a permitted or monitored landfill. Discussions have been initiated at county and state levels to determine an appropriate course of action, but no remedial action has yet been undertaken (Pierce, R., personal communication; Hedges, J., personal communication). A sample of leachate from the B&L Landfill taken in 1982 showed detectable levels of zinc (390 ug/L). Lead and copper were undetected at 20 ug/L. When resampled in August, 1983, B&L leachate contained 93 ug/L copper, 115 ug/L lead, and 673 ug/L zinc (Johnson and Norton 1985a). Based on these data, B&L Landfill appears not to be a major source of copper, lead, or zinc to Hylebos Creek. During low-flow conditions, the loading in Surprise Lake drain, into which runoff from B&L discharges, was below 0.04 lb/day for each metal. During high-flow conditions, zinc loading was estimated to be 0.24 lb/day. Data for copper and lead are unavailable from the high flow survey.

Log Sorting Yards--There are seven log sorting yards that drain into the upper portion of Hylebos Waterway. Together, their runoff contributes 42 percent of the quantified lead loading to the waterway, 35 percent of the copper loading, and 34 percent of the zinc loading. Among the seven log sorting yards, Cascade Timber yard No. 2 and Wasser Winters had the greatest loadings of copper, lead, and zinc. Weyerhaeuser had the lowest metal loadings. U.S. EPA chronic water quality criteria for the protection of saltwater aquatic life have been exceeded for zinc in Hylebos Waterway adjacent to the Murray Pacific yard No. 1 discharge. Corresponding acute criteria have been exceeded for copper off discharges from Wasser Winters, Murray Pacific yard No. 1, and at other sites throughout Hylebos Waterway (Norton and Johnson 1985a).

Log sorting yards along Hylebos Waterway have used ASARCO slag as ballast. This slag typically contains about 5,000 mg/kg each of lead and copper, and 18,000 mg/kg zinc (State of Washington Discharge Permit Application, 1971, ASARCO). Relative leaching rates for these compounds from the ballast are not known. Experiments conducted by Johnson et al. (1982) on slow-cooled and granulated slags from smelters indicated that cooling rate determines the leachability of particles within the slag, while particle size and shape determine the surface area available for leaching. In addition, the oxidative state of the slag as it cooled is a factor in determining complexation reactions, again potentially changing their relative leachability. Finally, the pH of the water to which the slag is exposed will determine the amount and relative leachability of each metal. The log sorting yard environment with relatively low pH enhances the leaching of these metals from slag. The variability in ratios of copper to lead, zinc to lead, and zinc to copper concentrations in surface runoff from the log sorting yards reported by Norton and Johnson (1985a) may indicate differences in type and particle size of slag used, time of slag deposition (composition may have changed over the years), and pH and redox conditions at each yard.

The extent of groundwater migration of copper, lead, and zinc from the log sorting yards has not yet been assessed, although it could be significant. Among the log sorting yards, the paved yard of Weyerhaeuser would be expected to have the least groundwater contamination because ASARCO slag was not used as ballast at this site and the yard has been paved, preventing infiltration of surface water.

Pennwalt Corporation--The loading data indicate that Pennwalt Corporation is the major source of copper and a lesser source of zinc and lead. The surficial chemistry data indicated elevated levels of copper, lead, and to a lesser extent, zinc, in intertidal stations along the Pennwalt waterfront. The firm has an NPDES permit to discharge lead. It is unclear why the effluent concentrations of other metals would be higher than influent concentrations.

Kaiser Aluminum and Chemical Company--CH2M HILL (1983) conducted a water management study for Kaiser Aluminum and Chemical Company to determine loadings of various contaminants in the storm sewer system on the Kaiser property. Copper and zinc were present in various locations on the property in concentrations ranging from <0.02 to 5.3 mg/L and <0.02 to 0.57 mg/L, respectively. Loadings in Kaiser Ditch just north of the facility parking lot were calculated at 0.20 lb/day copper and <0.20 lb/day zinc. The presence of these contaminants may be partially due to atmospheric fallout of particulates from the stack at Kaiser, although there are no available sampling data to quantify this. A single set of replicate analyses of sludge from the wet scrubber operations (Kaiser 1983) showed copper at 59 to 110 mg/kg, lead at 6 to 13 mg/kg, and zinc at 11 to 19 mg/kg, all on a wet-weight basis and thus not directly comparable to other data. However, the pH in the sludge ponds (>7) would render the metals relatively insoluble and limit their mobilization and migration into surface waters or groundwater. Loading data from Kaiser Ditch show it to be a significant source of metals to the waterway. However, the portion of the metal loading in Kaiser Ditch contributed by Kaiser Aluminum is not known. Cascade Timber Yard No. 2, Dunlap Towing, and Weyerhaeuser log sorting yards drain into or are immediately adjacent to the Kaiser Ditch and would contribute to the metal loading of this ditch.

General Metals--The General Metals scrap yard occupies 2,000 ft of the waterfront on the north shore of upper Hylebos Waterway. Due to the activities of storing, moving, and crushing metal, the firm is a potential source of metals. In addition, a portion of this site was used between 1972 and 1977 for the disposal of Occidental Chemical Corporation sludge pond wastes (Boys and Sceva 1979). The brine sludges making up this waste result from the sodium chloride purification process and contain up to 450 mg/kg lead and up to 30 mg/kg copper (Feller 1981). Therefore both surface water and groundwater discharge may be contributing metals to the waterway.

Tacoma Boatbuilding--Tacoma Boatbuilding is located on the north shore of the waterway adjacent to General Metals. Though sample density is inadequate for definitive conclusions, the greatest concentration of copper measured in Hylebos Waterway during the Tetra Tech survey, and the second highest concentration of zinc measured, were from a station along the north shore of the waterway adjacent to Tacoma Boatbuilding. Metal finishing and painting activities may result in metal contamination of the waterway from sandblasting grit containing a variety of metals and from antifouling paint containing copper or other metals. In a recent WDOE inspection of Tacoma Boatbuilding (circa 1983-84) discharge containing metal plating wastes was observed entering the Hylebos Waterway (Pierce, R., 15 July 1985, personal communication). Sandblasting materials have been used by Tacoma Boatbuilding during the decade they have occupied this site and their disposition have not been established.

7.2.10.4 Summary and Recommendations--

The spatial gradient of copper, lead, and zinc contamination in surficial sediments of Hylebos Waterway suggests the presence of multiple sources in the upper 7,000 ft of the waterway. Benthic and toxicity AET are only exceeded for these metals in inertidal sediments. Four sources have been found to account for most of the metal input to the upper waterway. All these sources are ongoing. These are listed below in order of the total copper, lead, and zinc loading of the discharge:

- Log Sorting Yards - Seven logging sort yards surround upper Hylebos Waterway. As a group, they contribute at least 11 lb/day metals (sum of copper, lead, and zinc) via surface water runoff. Additional loading via groundwater could be significant but is unquantified.

- Hylebos Creek - This discharge contributes 10 lb/day of metals to Hylebos Waterway. The greatest single contributor to this loading is Fife ditch, which joins the creek approximately 1,400 ft upstream from its mouth. The sources of metals to Fife ditch have not been investigated.

- Pennwalt Corporation - The various discharges from the facility contribute 4.3 lb/day of metals to Hylebos Waterway. The majority of this loading is attributable to the main outfall effuent (3 lb/day). The discharger is permitted through the NPDES program to discharge an average of 1 lb/day lead, and past discharges have been within the limit. It is not clear why the discharge contains significant quantities of copper and zinc.

- Kaiser Ditch - This discharge contributes 2.7 lb/day of copper, lead, and zinc combined to Hylebos Waterway. Available data are insufficient to establish if Kaiser Aluminum or the log sorting yards bordering the ditch bear the greater responsibility for the calculated loading.

The following recommendations may help define other sources of copper, lead, and zinc:

- Sample water and sediment within the drainage area served by Fife ditch to determine the source of metals in this discharge. Implement remedial actions, if feasible.

- Sample process and cooling water within the Pennwalt plant to determine the source of metals observed in the main discharge.

- Survey all discharges to Kaiser Ditch simultaneously to determine the source of metals.

- Pave or otherwise divert surface water runoff at the log sorting yards to reduce copper, lead, and zinc migration. Investigate migration of metals from these sites via groundwater.

- Sample of nearshore sediments and surface water runoff in the vicinity of General Metals and Tacoma Boatbuilding to establish whether these industries are sources of metals to Hylebos Waterway.

The four sources identified above contribute approximately 90 percent of the quantified loading of metals (copper, lead, zinc) to Hylebos Waterway. Reduction in metal input from these sources should result in a significant improvement in sediment quality. However, there are insufficient data on sediment transport, deposition, and mixing rates in Hylebos Waterway to predict the rate at which the recovery will proceed.

7.2.11 Mercury

7.2.11.1 Spatial Distribution--

The spatial gradient of mercury concentrations in surficial sediments of Hylebos Waterway are shown in Figure 7.2.39. Concentrations ranged from 0.05 to 1.0 mg/kg (dry weight), with two exceptions. The concentration of mercury exceeded 3 mg/kg dry weight at Tetra Tech Station HY-40, about 4,700 ft from the mouth of the waterway (Segment 5) and exceeded 15 mg/kg dry weight in intertidal sediments about 11,000 ft from the mouth of the waterway (Segment 2). Smaller mercury elevations in Segment 2 were found at two intertidal stations off Pennwalt, sampled in the Class II survey (Johnson and Prescott 1982), and two mid-waterway stations at 10,910 ft from the mouth sampled by Malins et al. (1980).

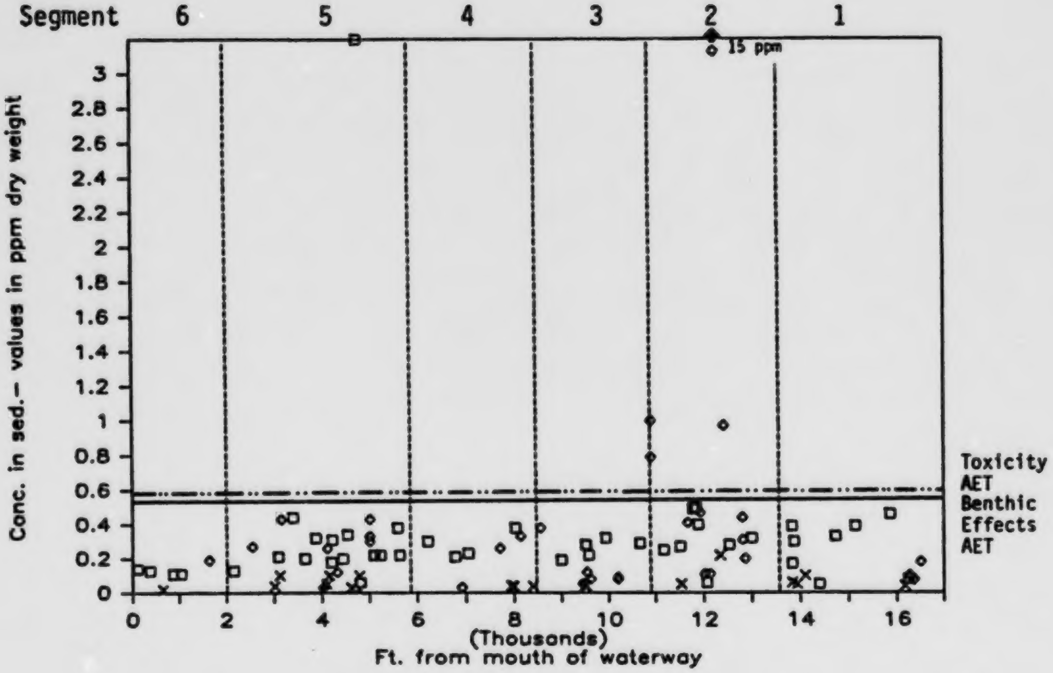
Sediment core data available for mercury in the Segment 5 problem area are limited to subtidal sediments from cores HY-63, HY-63A, HY-63B, and HY-63C. These cores are about 1,000 ft closer to the mouth of the waterway than Station HY-40 where elevated mercury concentrations were observed, and are directly off the docks at Occidental. Mercury concentrations decreased with depth in HY-63A, B01, from 0.38 mg/kg in the surface horizon to 0.14 mg/kg in the lowest horizon. Mercury concentrations increased with depth in HY-63, G01 (0.42-0.90 mg/kg), HY-63B, B03 (0.20-0.36 mg/kg) and HY-63C, B05 (0.21-0.50 mg/kg). There was no evidence in these cores or other Hylebos Waterway cores of the high levels of mercury observed primarily in intertidal sediments.

7.2.11.2 Loading Estimates--

Mercury has been measured in 20 ditches, drains, and seeps on Hylebos Waterway (Table 7.2.11). Loading from most of these sources ranged from 0.0001 to 0.001 lb/day. There has been no chemical analysis for mercury in drains HY-079 to HY-083, within 1,000 ft of the area of elevated sediments. Mercury measured in the 11th Street bridge storm drain (HY-078) had an average loading of only 0.000065 lb/day, not nearly enough to account for the elevation seen at Station HY-40 in the central part of the waterway. The mercury concentration in the drain at the northwest end of the Occidental property (HY-085) was 5 ug/L, with a corresponding loading of 0.000029 lb/day (Osborne 1980b).

7.2.11.3 Source Identification--

Only one potential source of mercury to Hylebos Waterway has been identified. According to Dames and Moore (1982), Mutual Fir Column, in business from 1921 to 1974, discharged methylmercuric phosphate through a sump on their property to a shallow bog in the 1950s. This company, which made porch columns, was located across the street from Buffelen Wood-working (Golocci, C., personal communication). J. Guizzetti (personal communication), of Buffelen Woodworking, does not recall that Mutual Fir Column treated their poles with methylmercuric phosphate or any other chemical. In addition, no mention in the literature could be found regarding use



□ Tetra Tech investigation - quantitated value
◇ Other investigations - quantitated value
x Other investigations - undetected value

Figure 7.2.39

CONCENTRATIONS OF MERCURY IN THE SURFICIAL SEDIMENTS OF THE HYLEBOS WATERWAY WITH DISTANCE FROM THE MOUTH OF THE WATERWAY
Concentrations on a dry weight basis

Table 7.2.11

MERCURY: SUMMARY OF LOADINGS FROM DISCHARGES TO HYLEBOS WATERWAY

Drain #	Drain Name	Flow (MGD) (Avg. and Range) (# of Observations)	Period of Observations for Contaminant Concentrations	Concentration (ug/l) (Avg. and Range) (# of Observations)	Loading (lbs/day) (Avg. and Range)
INDUSTRIAL DISCHARGES					
HK-052	Kaiser Ditch	1.9 (0.23-2.9) (n=8)	9/23/80-4/17/84	0.36 (0.05-1) (n=7)	0.0057 (0.00079-0.016)
HY-058	Pennwalt Main Outfall	11 (9.4-12) (n=2)	6/3/80-6/2/81	0.30 --- (n=2)	0.28 ---
HY-704	Sound Refining Main Effluent	0.053 --- (n=1)	6/3/80-6/30/81	0.50 (0.080-0.83) (n=2)	0.00022 (0.000035-0.00037)
DRAINS AND RUNOFF					
HM-028	Morningside Ditch	0.66 (0.49-0.78) (n=3)	9/23/80-11/7/83	0.24 (0.07-0.49) (n=4)	0.0013 (0.00039-0.0027)
HY-016	Crack in Bulkhead	0.071 --- (n=1)	9/24/80-6/30/81	0.15 (0.080-0.21) (n=2)	0.000089 (0.000047-0.00012)
HY-017	Twelve-inch Corrugated Steel Pipe	0.0039 --- (n=1)	6/30/81	0.17 --- (n=1)	0.0000055 ---
HY-018	Eight-inch Steel Pipe	0.001 --- (n=1)	6/30/81	0.29 --- (n=1)	0.000002 ---
HY-019	Twenty-four-inch Corrugated Steel Pipe	0.026 --- (n=1)	6/30/81	0.17 --- (n=1)	0.000037 ---
HY-023	Eighteen-inch Concrete Pipe	0.050 --- (n=1)	4/28/82	0.26 --- (n=1)	0.00011 ---
HY-054	East Channel Ditch	0.0055 (0.0014-0.01) (n=3)	9/23/80-5/17/84	3.6 (0.14-11) (n=5)	0.00017 (0.000006-0.00051)
HY-055	Eight-inch PVC Pipe	0.0046 --- (n=1)	4/7/81-5/31/83	2.9 (0.8-5) (n=2)	0.00011 (0.000031-0.00019)
HY-056	Six-inch Concrete Pipe (currently disconnected)	0.017 (0.0043-0.029) (n=2)	6/3/80-6/2/81	12 (0.60-29) (n=3)	0.0017 (0.000085-0.0041)

Table7.2.11(cont'd)

HY-066	Lincoln Avenue Storm Drain	0.043 (0.029-0.05) (n=3)	5/31/84	0.34 --- (n=1)	0.00012 ---
HY-078	Twelve-inch Concrete Pipe	0.025 (0.02-0.03) (n=2)	5/31/84	0.31 --- (n=1)	0.000065 ---
HY-085	Seven Steel Pipes	0.0007 --- (n=1)	9/23/80	5 --- (n=1)	0.000029 ---
HY-708	Pennwalt East Storm Drain (currently disconnected)	0.0043 --- (n=1)	4/7/81	6.3 --- (n=1)	0.00023 ---
HY-709	Pennwalt Sewer Pipe (currently disconnected)	0.0066 (0.0058-0.0074) (n=2)	6/3/80-6/2/81	5.8 (0.38-16) (n=3)	0.00032 (0.000021-0.00088)
GROUNDWATER BANK SEEPS					
HY-700	Pennwalt East Seep	0.00079 (0.00036-0.0014) (n=3)	6/3/80-4/18/84	6.9 (2-12) (n=4)	0.000045 (0.000013-0.000079)
HY-701	Pennwalt West Seep	0.0012 (0.001-0.0014) (n=2)	9/23/80-6/2/81	9.5 (3-16) (n=2)	0.000096 ---
HYLEBOS CREEK					
HC-000	Hylebos Creek WDOE Station 17	16 (4.9-44) (n=5)	11/8/83-9/5/84	0.15 (0.051-0.330) (n=4)	0.020 (0.0068-0.044)

NOTE: Mercury has been analyzed for but not detected in the following drains (numbers in parentheses represent numbers of analyses and detection limits): HY-077 (1, 0.2 ug/l); HY-707 (5, 0.2 ug/l).

of methylmercuric phosphate for wood treating (Sax 1984; Hawley 1981). In any case, the only probable route of contamination from this source would be through groundwater seepage. The distance from this property to the area of elevated mercury concentration makes this a doubtful source, particularly since elevated mercury concentrations were restricted to an isolated site in the central waterway.

Historical industrial processes at Occidental Chemical were investigated to determine whether they had ever used a mercury cell process in chlorine manufacture. According to F. Monahan (personal communication), the company has never used this process. Similarly, the elevated concentrations of mercury in intertidal sediments off Pennwalt Corporation are not known to be a result of industrial processes. Other possibly unknown historical activities at this site may be responsible for this contamination.

7.2.11.4 Summary and Recommendations

Sources of mercury were not obvious on the basis of gradients or patterns of contamination. Elevated mercury concentrations in Segment 5 occurred at a single station only (Station HY-40). Potential sources are unknown. In Segment 2, some mercury may be entering the waterway from Pennwalt Corporation property; however, the origin of this contaminant is not known.

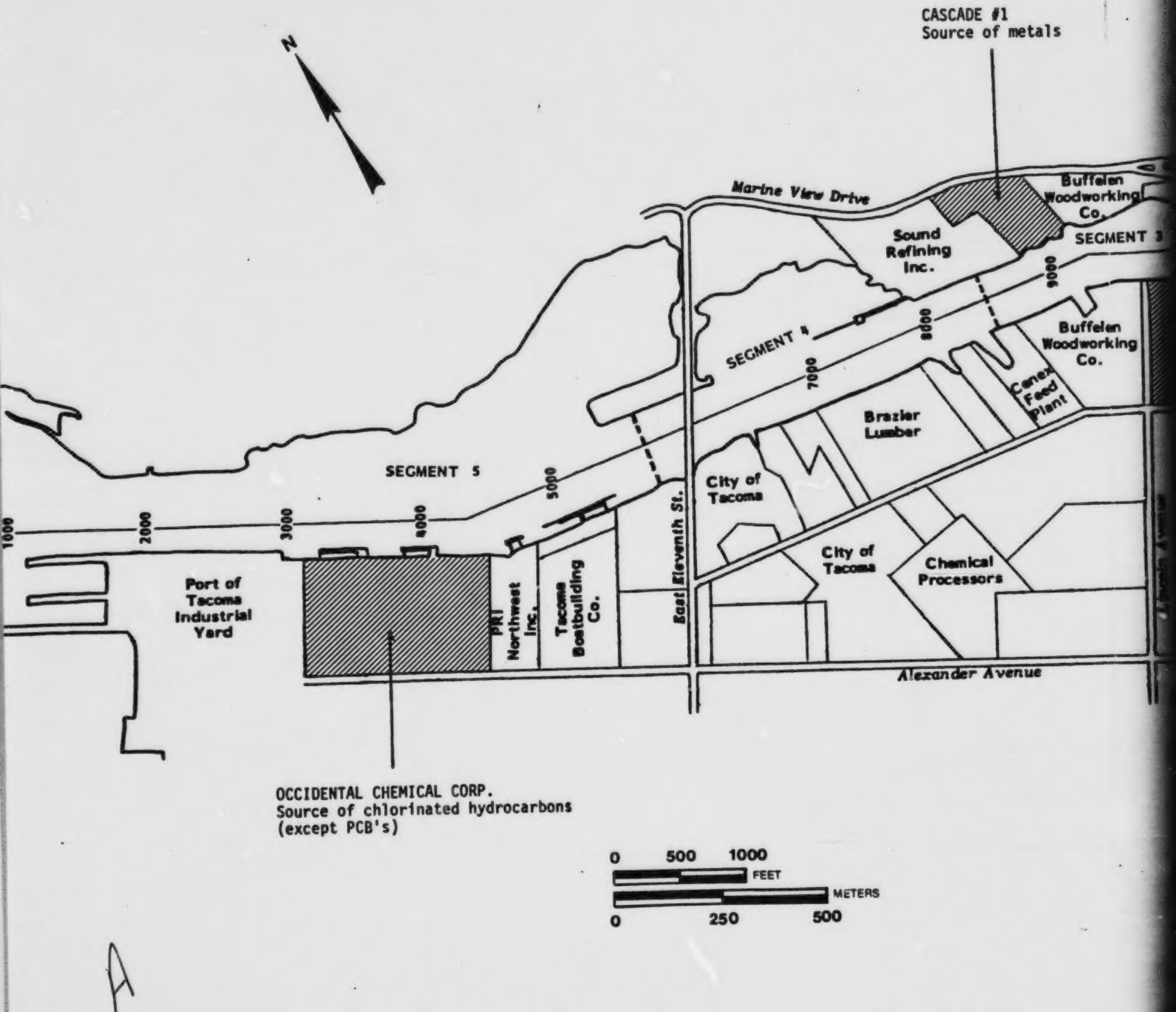
The source of mercury at Pennwalt should be investigated and source control should be implemented if feasible.

7.2.12 Hylebos Waterway: Summary and Recommendations

7.2.12.1 Summary--

Results of the source identification efforts in Hylebos Waterway are summarized in Figure 7.2.40. Nine contaminants or contaminant groups were designated to be of concern in Hylebos Waterway. One or more sources could be identified with a high degree of certainty for the chlorinated hydrocarbons, aromatic hydrocarbons, and metals. PCB sources in Hylebos Waterway could not be clearly identified as historical or ongoing. Exposure of historically contaminated sediments may be contributing to the patchy distribution of PCBs in Hylebos Waterway. The spatial gradient of contamination for the pentachlorocylcopentane isomer clearly implicates a specific source (i.e., Occidental Chemical Corporation). This source probably contributes a large number of chlorinated compounds with covarying concentrations in Hylebos Waterway sediments. Only some of these compounds have been identified.

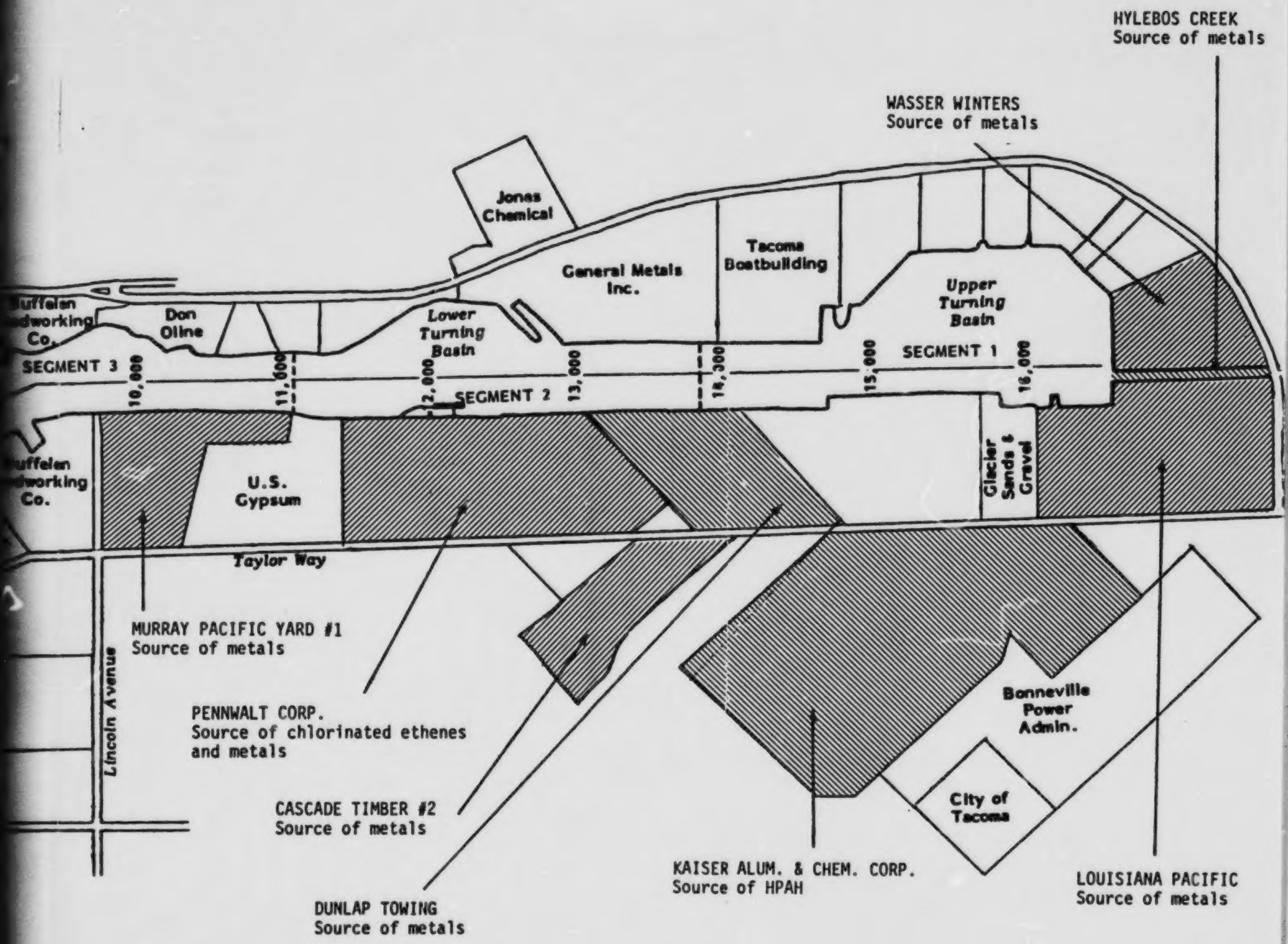
Occidental Chemical Corporation is implicated as the major source of chlorinated hydrocarbons (i.e., chlorinated benzenes, butadienes, and ethenes) to Hylebos Waterway. Historically, the chlorinated organic compounds entered the waterway via direct discharge from the chlorine production facilities and the solvents plant, and via groundwater from spills and on-site waste disposal. At present, the chlorinated benzenes and butadienes enter the waterway principally through the main plant outfall. Chlorinated ethenes presently enter the waterway principally through groundwater and,



CASCADE #1
Source of metals

OCCIDENTAL CHEMICAL CORP.
Source of chlorinated hydrocarbons
(except PCB's)

A



LEGEND:

▨ KNOWN OR PROBABLE SOURCE

Figure 7.2.40

SOURCES OF CONTAMINANTS TO THE HYLEBOS WATERWAY

B

to a lesser extent, through the main outfall. The daily loading of the chlorinated organic contaminants of concern to Hylebos Waterway from Occidental Chemical Corporation is currently more than six times that of any other source along the waterway.

Pennwalt Corporation appears to be a current source of chlorinated ethenes, arsenic, copper, lead, zinc, and mercury. The chlorinated ethenes are presently discharged to the waterway through the main plant outfall and through groundwater which has become contaminated as a result of past on-site waste disposal. Arsenic presently enters the waterway via the main outfall and through groundwater that has become contaminated as a result of on-site disposal of a sodium arsenite pesticide. The main plant outfall appears to be a source of copper, lead, zinc, and mercury based on effluent analyses and loading estimates. However, it is unclear why process effluents at Pennwalt contain elevated concentrations of these metals.

Kaiser Aluminum and Chemical Corporation has historically been a major source of HPAH to Hylebos Waterway, principally via discharge through Kaiser Ditch. Discharge of PAH through this ditch was much greater in the past than it is at present, but there is evidence that some release of PAH continues. Kaiser Ditch is also a source of arsenic, copper, lead, zinc, and mercury. The relative contributions of Kaiser Aluminum and Chemical and other properties bordering the ditch are unknown.

Hylebos Creek is an ongoing source of arsenic, copper, lead, and zinc. The U.S. Gypsum landfill and the B&L Landfill are major contributors to the arsenic load in Hylebos Creek. The arsenic contribution from the U.S. Gypsum landfill should decrease with time as a result of recent remedial action. Fife Ditch is the major contributor of zinc to Hylebos Creek.

Unpaved or partially paved log sorting yards bordering Hylebos Waterway are sources of arsenic, copper, lead, and zinc because of the use of ASARCO slag as ballast. As a group, these log sorting yards contribute approximately 11 lb/day of arsenic and 11 lb/day of metals (copper, lead, and zinc) via surface runoff (contribution of Dunlap Towing was not quantified nor included in total loading). Additional loading from the log sorting yards via groundwater could be significant but is unquantified.

7.2.12.2 Recommendations--

Specific recommendations have been summarized at the end of each contaminant section in Section 7.2. General recommendations for Hylebos Waterway are listed below.

- Information on vertical and horizontal gradients of contamination presented in this report should be used in evaluating future requests for dredging permits and in determining the appropriate chemical analyses prior to dredging. For example, prior to Pennwalt's 1982 dredging, the firm analyzed surface sediments in the area to be dredged for organic contaminants, and subsurface sediments for metals (High 1982). Based on the data presented herein, peak concentrations of organic contaminants are typically found in subsurface sediments, while those of metals are generally found in surface sediments. As a consequence of the dredging by Pennwalt, contaminated sediments have been uncovered. In these newly exposed sediments, concentrations of PCBs, chlorinated hydrocarbons, PAH, and dibenzofuran were several times greater than those in nearby surface sediment.

- The depth of sediment contamination often exceeded the effective depth of penetration of the gravity and box core samplers used in these investigations. Deeper samples probably requiring a drilling program will be needed to assess adequately the vertical extent of contamination prior to sediment removal efforts.

7.3 SITCUM WATERWAY

7.3.1 Introduction

It is uncertain when Sitcum Waterway was first created from the tidal flats of the Puyallup River, but the waterway was filled with log rafts in a 1923 photo of Commencement Bay. In this photo, the waterway was approximately twice its present width. Little change appears in photographs and charts of the waterway between 1923 and 1946. Since that time, nine dredging operations have removed about 3.5 x 10^6 yd^3 of waterway sediment (Table 7.3.1). A portion of the dredged material was used as fill to form new terminals along the north shore, reducing the width of the waterway to its present size. This filled area comprises Terminal 7 and was completed in 1973. The south shore of the waterway was dredged to form the West Sitcum terminal in 1979. The channel has been dredged twice since 1979 for maintenance at Berth B, Terminal 7 and along the south shore of the waterway mouth (Norton and Johnson 1985b; Port of Tacoma dredging Permits 6022, 6837).

Industries that used to occupy Sitcum Waterway waterfront include lumber and wood products companies, railroad yards, and Time Oil Company, an oil storage facility in the area from the 1930s to 1950s (Ruckelshaus 1985). Current industries along the waterway are shown in Figure 7.3.1. The south shore is owned by the Port of Tacoma and leased by Sealand for storage, shipping, and receiving facilities. An office building at the head of the waterway houses the Port of Tacoma executive offices, formerly (until 1982) located at the end of the south Sitcum peninsula (Dames and Moore 1982). The north waterfront is occupied by the Port's Terminal 7, with facilities for container handling and bulk unloading of alumina, various ores, and concentrates. Two alumina storage domes at the terminal, built in 1966 and 1968, have a combined capacity of 136,000 mt (Norton and Johnson 1985b).

Discharges to Sitcum Waterway, shown in Figure 7.3.1, include seventeen storm drains and numerous discharges of unknown origin (presumably runoff). The storm drain with the greatest discharge volume is SI-172, which serves a large industrialized area between East 11th Street and Lincoln Avenue. Two NPDES permitted industries (Georgia Pacific Corporation and Purex Corporation) discharge cooling water to Sitcum Waterway through this drain. Emergency overflow from a sewer lift station discharges to Sitcum Waterway via SI-176.

The bottom sediments of Sitcum Waterway have been heavily sampled, particularly for the trace metals. Locations of surficial sediment chemistry sampling stations are shown in Figure 7.3.2, including both Tetra Tech stations sampled as part of the Superfund investigations and all available historical data. Although the Tetra Tech sampling was confined principally to the central waterway, a great deal of historical data were available to check for cross-waterway gradients of contamination.

Preceding page blank

Table 7.3.1

DREDGING HISTORY OF SITCUM WATERWAY

Completed	Contract Number	Purpose and Amount	Disposal
1946	19	Initial dredging 2,736,800 yd^3	Landfill bordered by east 11th Street, Lincoln Avenue, Milwaukee Way, and Port of Tacoma Road ("quadrangle")
1956	49	385,000 yd^3	Landfill adjacent to Sitcum Waterway behind Terminal 7, Berth A
October 1961	99	Dredging for Terminal 7 Berths A & B 43,000 yd^3	Commencement Bay deepwater disposal site
February 1966	179	Dredging for Terminal 7 Berth C	(no information)
June 1968	214	77,947 yd^3	Commencement Bay deepwater disposal site
1973	339	Dredging for Terminal 7 Berth D	(no information)
March 1979	456	Made West Sitcum terminal Sealand (formerly TOTE facility), 82,000 yd^3	Landfill west side of Sitcum Waterway,Sealand (formerly TOTE facility)
September 1982	488	Maintenance dredging Terminal 7, Berth B 29,708 yd^3	Four Mile Rock, Elliott Bay
February 1983	525	West shoal dredging 90,000 yd^3	Commencement Bay deepwater disposal site

Source: Norton and Johnson (1985); original information from Gary Kucinski, Port of Tacoma

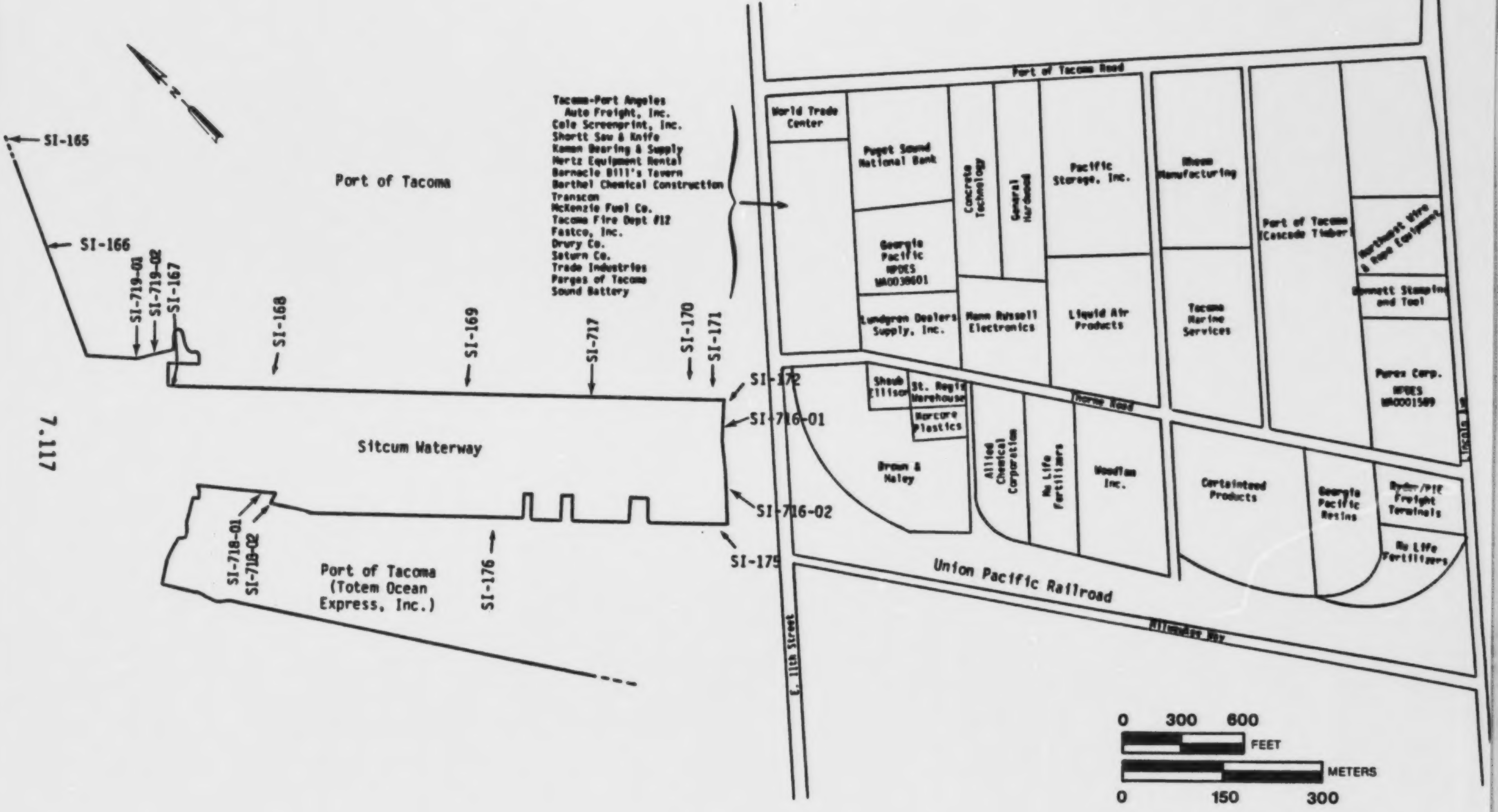


Figure 7.3.1

INDUSTRIES WITHIN THE SITCUM WATERWAY DRAINAGE AREA

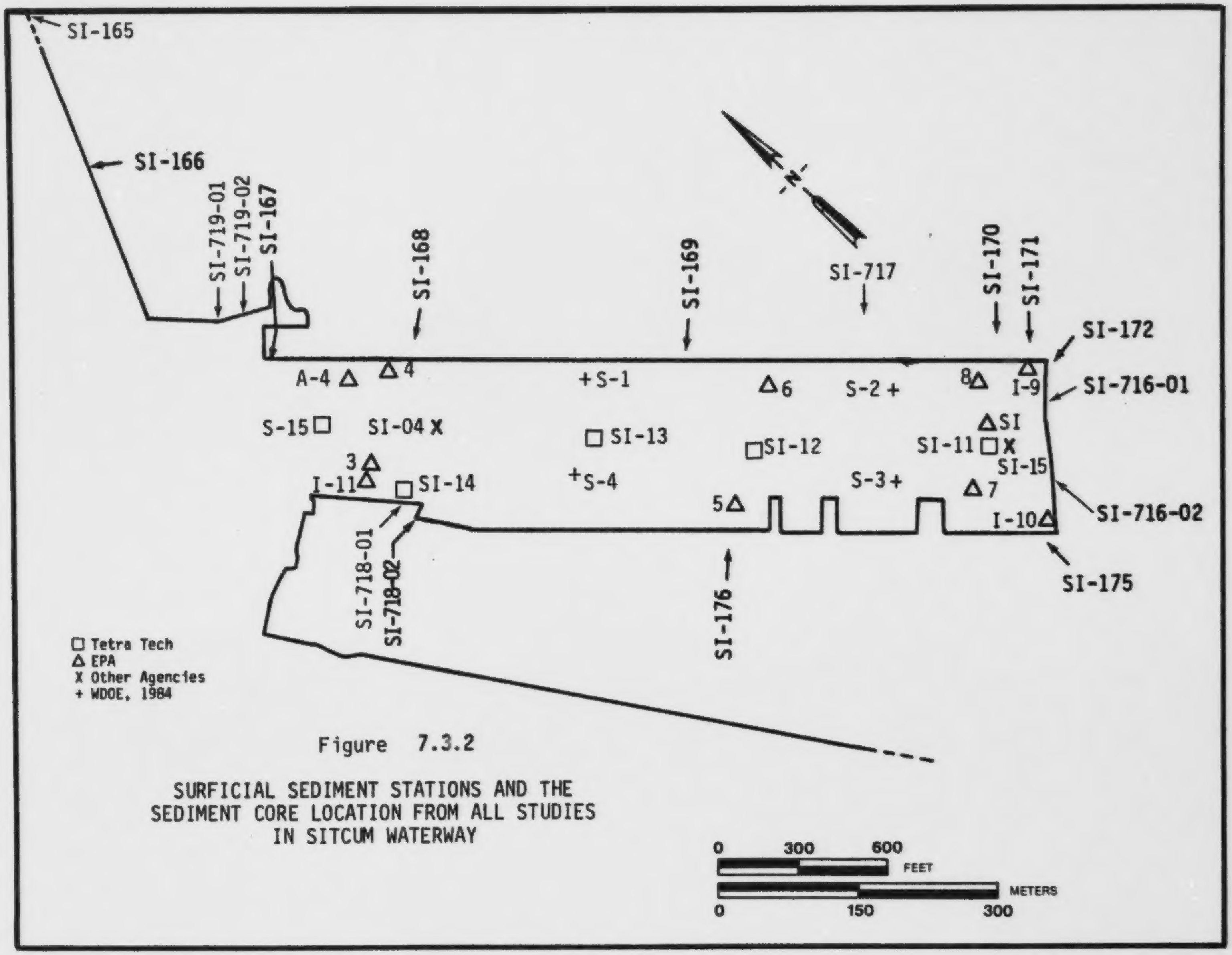


Figure 7.3.2

SURFICIAL SEDIMENT STATIONS AND THE SEDIMENT CORE LOCATION FROM ALL STUDIES IN SITCUM WATERWAY

The following were defined as preliminary contaminants of concern in Sitcum Waterway:

Organic Compounds	Inorganic Substances
Aromatic hydrocarbons	Arsenic
Dibenzofuran	Copper
	Lead
	Zinc

A discussion of spatial gradients, known discharges, and other potential sources of these contaminants can be found in Sections 7.3.2 (aromatic hydrocarbons and dibenzofuran) and 7.3.3 (metals).

Concentrations of each of these substances were later determined to exceed toxicity or benthic AET in sediments from at least one station in Sitcum Waterway. Additional substances present above AET (see Table 6.14 in Section 6) but not yet evaluated for sources include

Substance	Station Where AET Exceeded
N-nitrosodiphenylamine	SI-12
1-Methyl-(2-methylethylbenzene)	SI-11
Diterpenoid hydrocarbons	SI-12

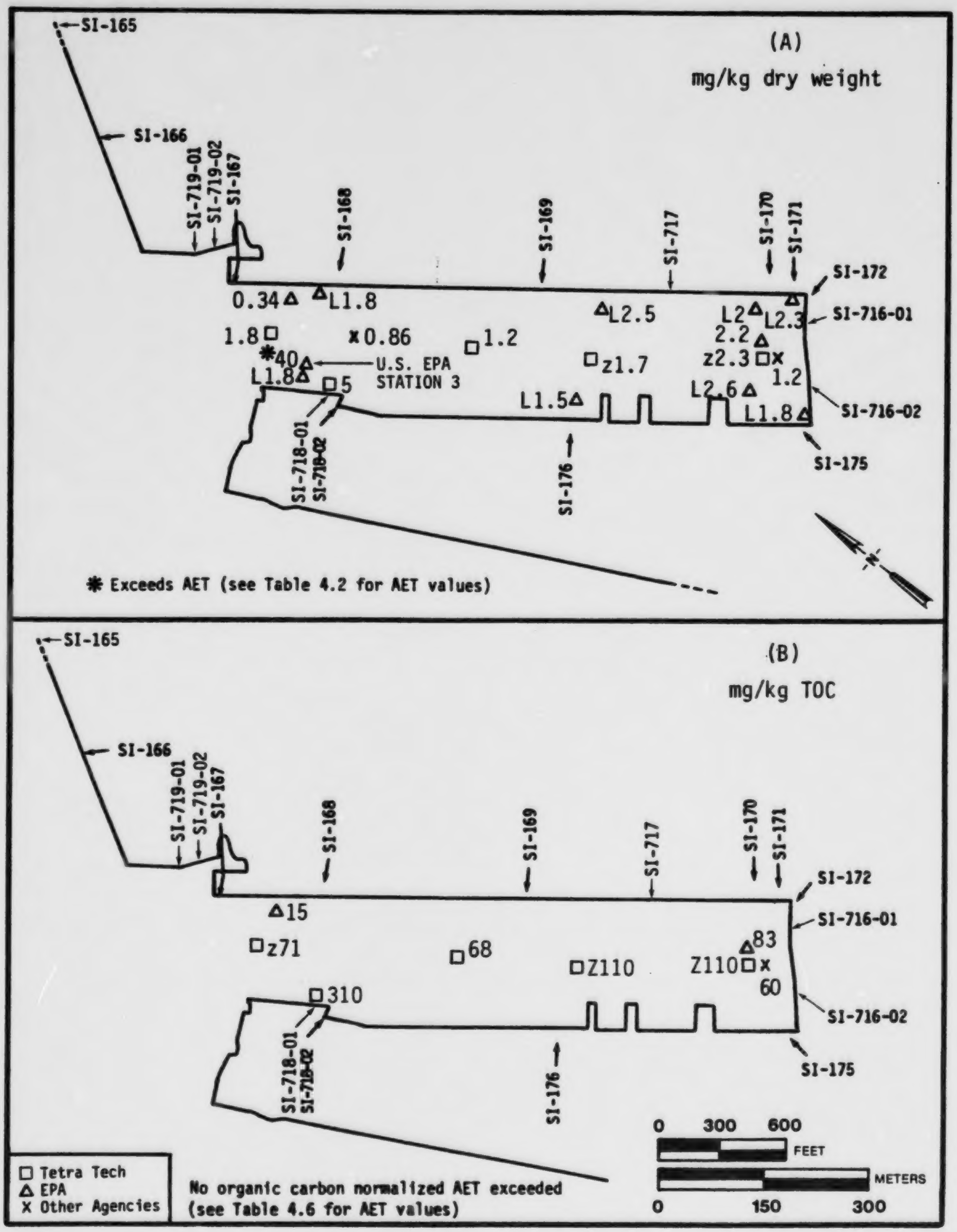
The latter two compounds or compound groups are only tentatively identified. These additional potential problem chemicals are not discussed further.

Average mass flux estimates were calculated for arsenic, copper, lead, and zinc to enable a comparison of mass loadings of these contaminants relative to their sediment concentrations. Insufficient source data were available to calculate mass flux estimates for the other priority contaminants. The mass flux estimates were evaluated using average concentrations of the metals in sediments from all present and historical stations according to the procedures and criteria outlined in Section 2.12.3.2. All of the source-derived mass fluxes were within an order of magnitude of the concentration-derived mass fluxes. Therefore, according to the uncertainty criteria for this analysis, no data gaps were indicated in accounting for major sources of arsenic, copper, lead, or zinc.

7.3.2 Aromatic Hydrocarbons and Dibenzofuran

7.3.2.1 Spatial Distribution--

Low and high molecular weight polycyclic aromatic hydrocarbons (LPAH and HPAH) and dibenzofuran have been identified as contaminants of concern in Sitcum Waterway. The spatial pattern of contamination in surficial sediments of the waterway was generally similar for all three contaminants or contaminant groups (Figures 7.3.3-7.3.5). Based on data (dry-weight basis) from the Tetra Tech stations in the center of the waterway, there was evidence of a decreasing gradient from the head to the mouth of the



✱ Exceeds AET (see Table 4.2 for AET values)

No organic carbon normalized AET exceeded (see Table 4.6 for AET values)

Figure 7.3.3

CONCENTRATIONS OF LOW MOLECULAR WEIGHT PAH IN SURFICIAL SEDIMENTS OF SITCUM WATERWAY

L = At least one of the components of the group was undetected, sum included the detection limit.
Z = Data corrected for blank.

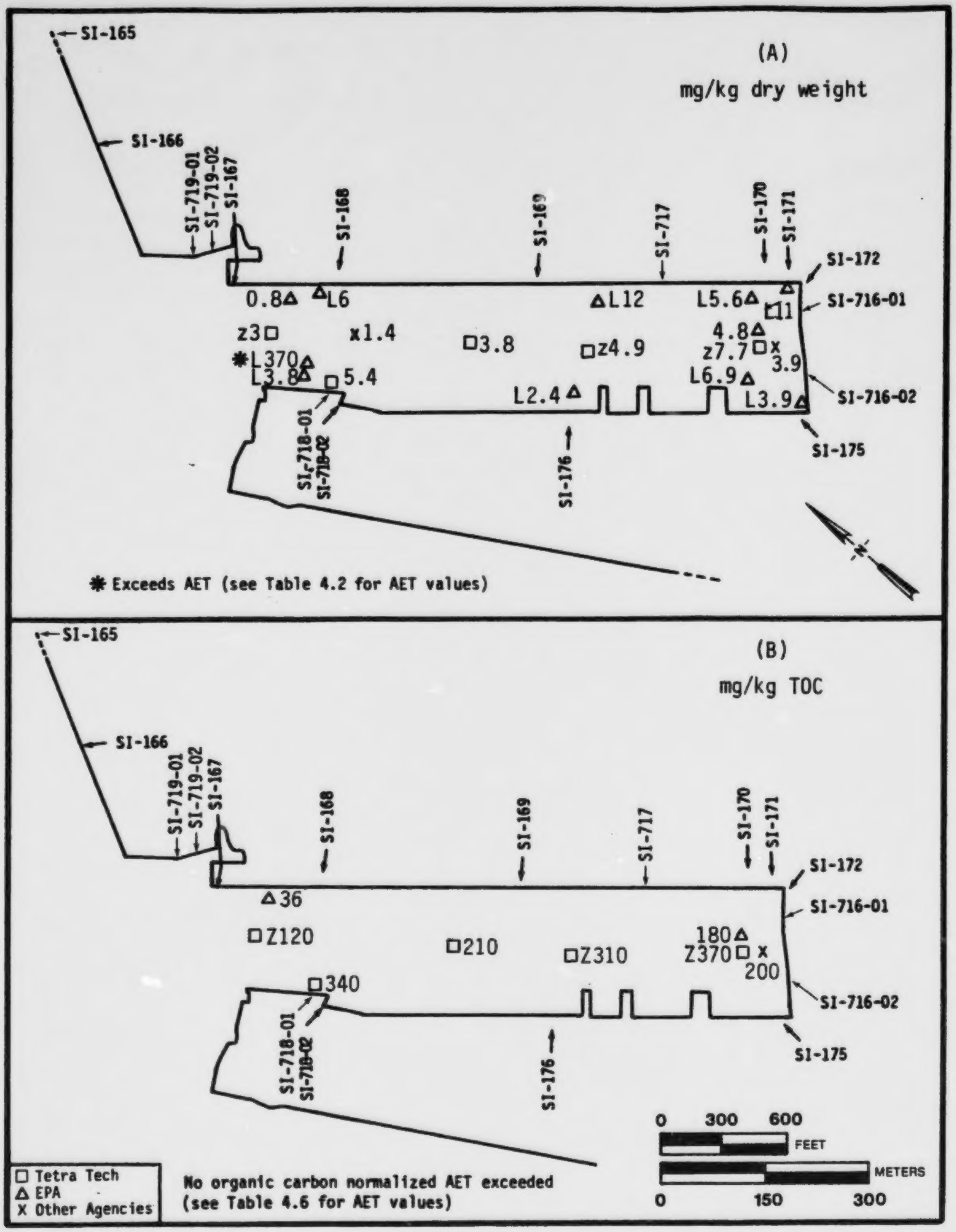


Figure 7.3.4

CONCENTRATIONS OF HIGH MOLECULAR WEIGHT PAH IN SURFICIAL SEDIMENTS OF SITCUM WATERWAY

z = data corrected for blank

L = At least one of the components of the group was undected, sum included the detection limit.

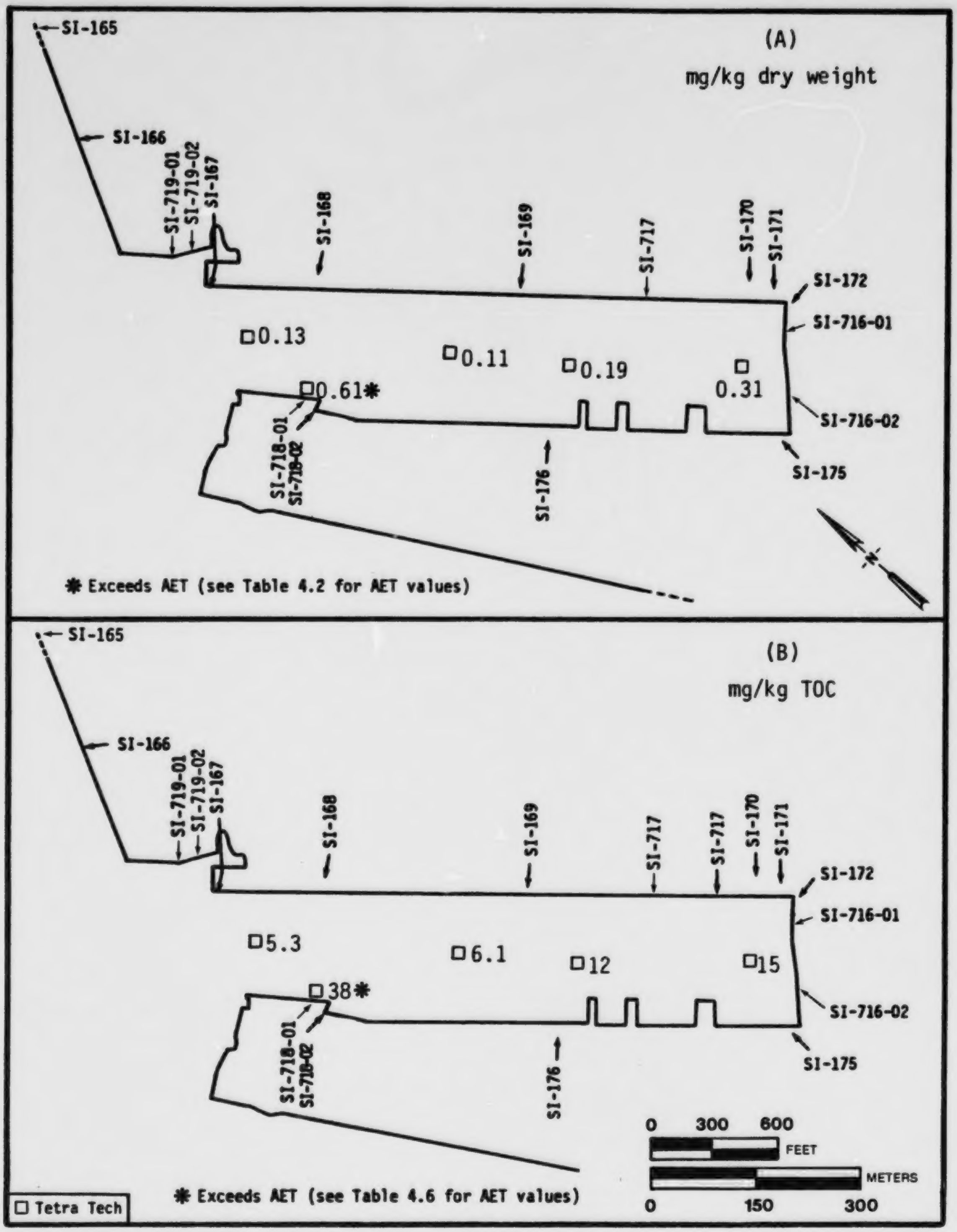


Figure 7.3.5

CONCENTRATIONS OF DIBENZOFURAN IN
SURFICIAL SEDIMENTS OF SITCUM WATERWAY

waterway. However, when all available data were considered, no definitive gradient was apparent and the distribution was patchy. TOC data were available for only some of the stations in the combined data sets. However, there was no gradient observed after concentrations were normalized to organic carbon content (Figures 7.3.3-7.3.5).

An isolated area with elevated concentrations (dry weight) was apparent for LPAH, HPAH, and dibenzofuran near the waterway mouth along the southern shore (Tetra Tech SI-14 and U.S. EPA Station 3; see locations in Figure 7.3.2). These stations are located near the Sealand facility in an area recently disturbed by dredging. Therefore, it is likely that the observed elevated concentrations were from historical deposition.

One sediment core sample was collected at the head of Sitcum Waterway along the Terminal 7 pier face, near the northeast corner. Concentrations (ug/kg dry weight) with depth in the sediment were

	LPAH	HPAH	Dibenzofuran
Horizon 1 (0-0.10 m)	2,040	8,100	235
Horizon 2 (0.10-0.30 m)	6,900	25,300	430
Horizon 3 (0.30-0.41 m)	1,740	4,500	170

These data indicate a subsurface maximum in PAH and dibenzofuran concentrations. Concentrations in Horizon 2 were two-fold to five-fold greater than those in shallower or deeper horizons and exceeded toxicity and benthic AET. Concentrations in Horizons 1 and 3 did not exceed AET.

7.3.2.2 Loading Estimates--

The effluent from drains SI-172 and SI-175 have been analyzed for LPAH and HPAH. In two analyses with detection limits of 10 ug/L, no LPAH or HPAH were measured in the effluent from drain SI-175. Only a single LPAH, phenanthrene, was detected in six analyses of the effluent from drain SI-172. On one occasion, the phenanthrene concentration was reported to be less than 0.30 ug/L (WDOE unpublished). Only a single HPAH, pyrene, has been detected in discharge from drain SI-172. In one of six analyses, the pyrene concentration was less than 0.20 ug/L (WDOE unpublished). No HPAH were reported in five other analyses with detection limits ranging from 0.1 to 10 ug/L. Dibenzofuran was undetected at 0.1 ug/L in two analyses of the SI-172 effluent.

7.3.2.3 Source Identification--

No apparent sources of PAH and dibenzofuran can be identified. Storm drains and runoff into the waterway are a potential source. There is no documented source to account for the area near the south shore at the mouth of the waterway where LPAH and dibenzofuran concentrations exceed those elsewhere in the waterway. Tacoma Boatbuilding Company was located on the waterfront in this area until the 1970s. The company relocated to Hylebos Waterway after their operation was destroyed by fire, and the site was occupied by Aero Jet, a hovercraft manufacturer. After the departure of Aero Jet (late 1975), the Port of Tacoma moved their offices to this site. In 1982, the Port moved their offices to the head of the waterway, and the site at the mouth was subsequently leased to Totem Ocean Trailer Express, then to Sealand, the present leasee. It is possible that activities of one or more of the previous occupants contributed to the PAH in the waterway sediments. The fire at Tacoma Boatbuilding would also have contributed an unquantifiable amount of PAH to the waterway sediments. However, another likely cause of the elevated contaminants in this area is exposure of buried contaminated sediments during the dredging of several feet of sediments by the Port of Tacoma in the early 1980s.

Milwaukee Railroad was located on the south shore of Sitcum Waterway until 1980. According to Dames and Moore (1982), numerous solid and liquid spills have occurred in this area. The contents of these spills are unknown and the associated potential for release of contaminants to Sitcum Waterway from the spills and railway operations cannot be evaluated. Time Oil Company (gasoline and oil storage) was located somewhere in Sitcum Waterway area from the 1930s to 1950s. No other information is available on this company.

Based on a review of WDOE Environmental Complaint Files, 1978-1985, two recent spills could have contributed contaminants to the waterway. On March 25, 1981, 150 gal of Bunker C oil was spilled at the intersection of East 11th Street and Port of Tacoma Road. On November 12, 1983, less than 500 gal of diesel and Bunker C oil were spilled in Sitcum Waterway (point of discharge not established).

7.3.2.4 Summary and Recommendations--

No major sources of PAH and dibenzofuran could be identified. General discharges by storm drains and runoff is the major suspected source. The isolated area near the mouth of the waterway where highest LPAH and dibenzofuran concentrations were measured is most likely attributable to a dredging project that may have exposed deeper, more contaminated sediments. The composition of PAH (i.e., an abnormally high benzo(a)pyrene concentration) at this station was unlike that of other station in the waterway.

General controls on petroleum products and suspended matter in storm drain systems should be considered.

7.3.3 Metals

7.3.3.1 Spatial Distribution--

The spatial distributions of copper, zinc, and lead in surficial sediments of Sitcum Waterway are shown in Figures 7.3.6-7.3.8. Data from Tetra Tech stations suggested a possible trend in the central waterway with concentrations decreasing towards the mouth. This trend disappeared when all available data were considered. Instead, the distribution was patchy, with concentration elevations along the north shore and a definite hot spot in the northeast corner (U.S. EPA station). The distribution of arsenic was patchy with

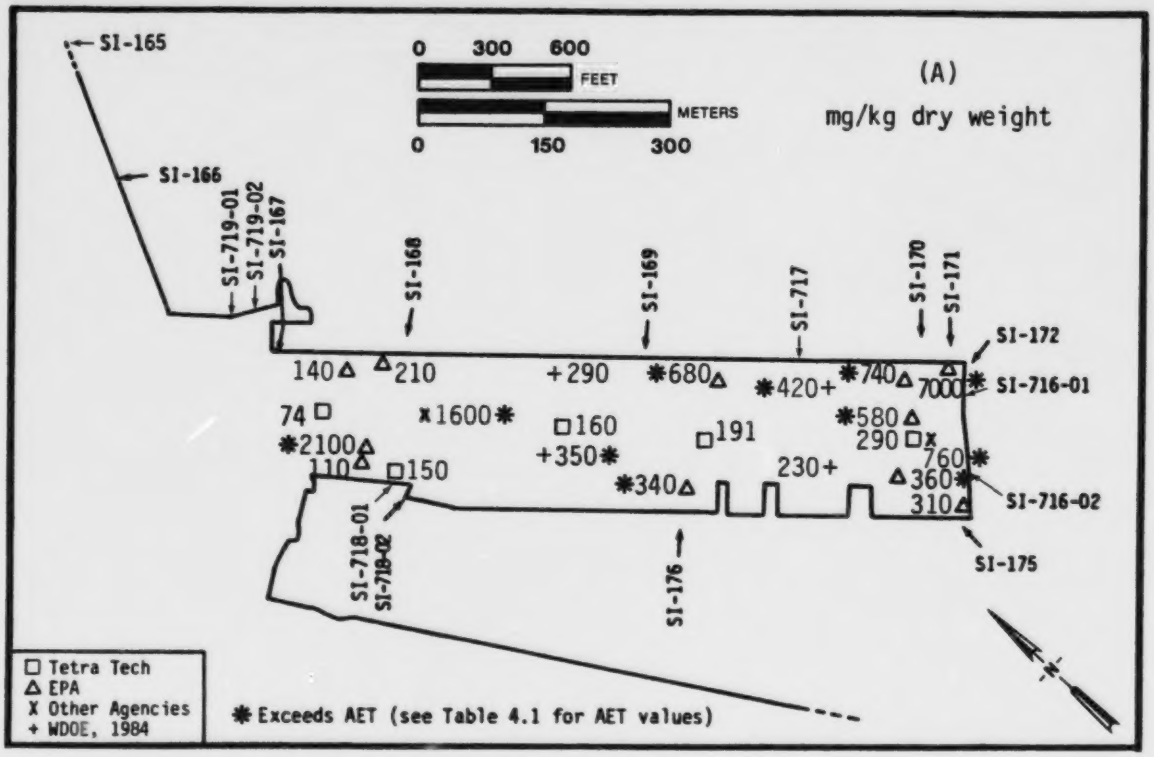


Figure 7.3.6

CONCENTRATIONS OF COPPER IN
SURFICIAL SEDIMENTS OF SITCUM WATERWAY

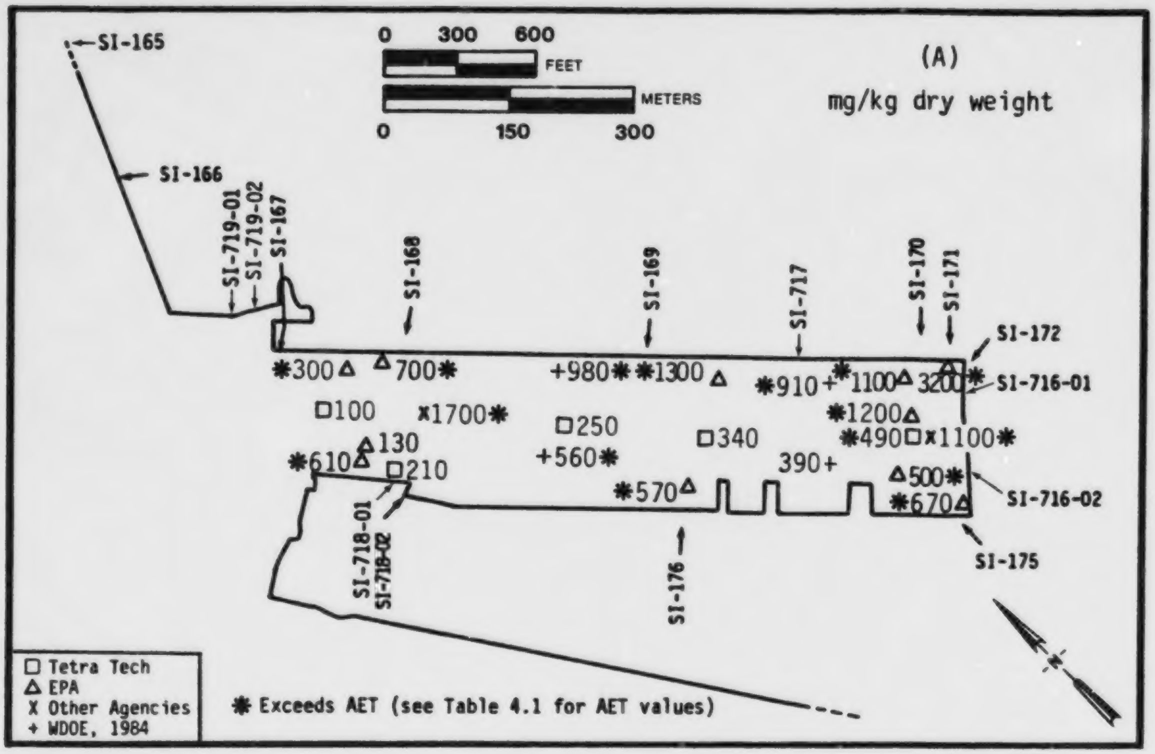


Figure 7.3.7

CONCENTRATIONS OF ZINC IN
SURFICIAL SEDIMENTS OF SITCUM WATERWAY

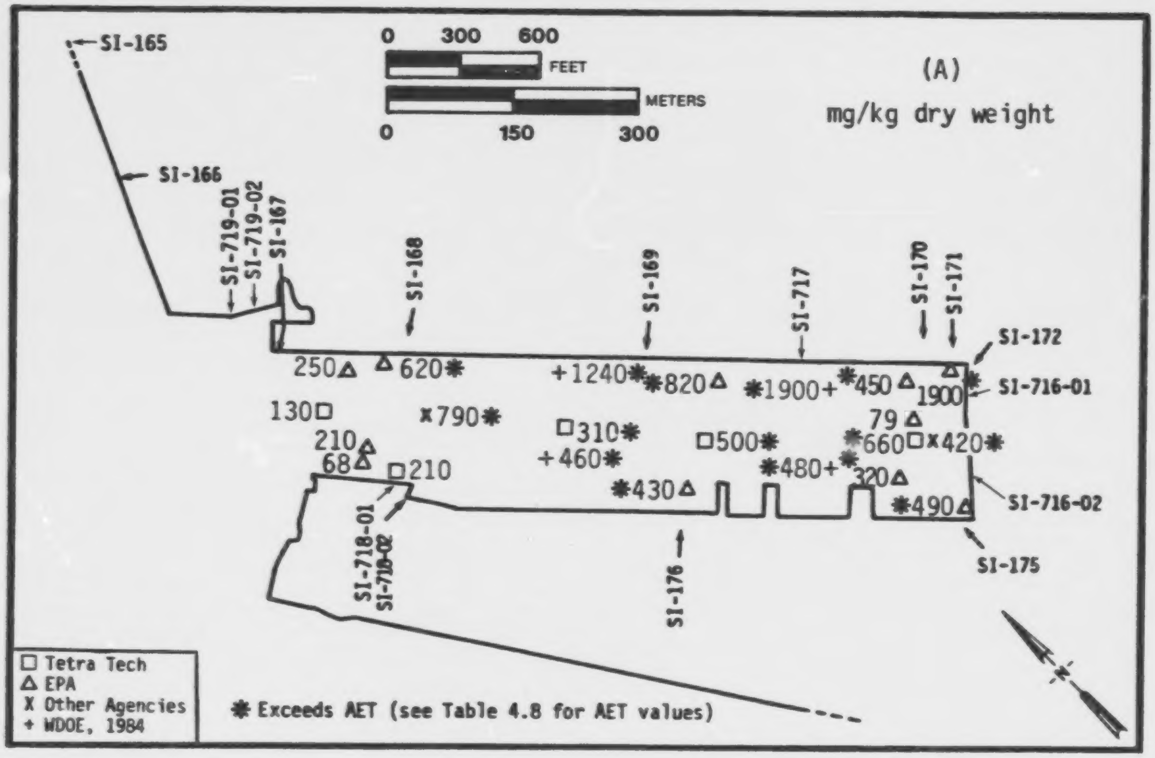


Figure 7.3.8

CONCENTRATIONS OF LEAD IN
SURFICIAL SEDIMENTS OF SITCUM WATERWAY

no apparent gradients or hot spots (Figure 7.3.9). Normalization of metals concentrations to percent fine-grained material in Sitcum Waterway sediments did not substantially change the relative distribution observed. Grain size data were not available for several stations with the highest metals concentrations.

One sediment core sample was collected at the head of Sitcum Waterway along the Terminal 7 pier on the north shore. The data (Table 7.3.2) indicate a subsurface maximum for all the metals of concern. The second horizon (0.1-0.3 m) had greater concentrations of copper, lead, zinc, and arsenic than did horizons above and below.

7.3.3.2 Loading Estimates--

There are seven discharges to Sitcum Waterway for which calculated loadings of arsenic, copper, lead, and zinc were available. Loadings from the seven storm drains, along with data on concentrations and flow from each source, are summarized in Tables 7.3.3-7.3.6. These determinations were made using all available loading data. Drain SI-172, a 60-in concrete pipe storm drainage outfall entering the northeast corner of the waterway, discharged 93 percent of the total arsenic loading to Sitcum Waterway. The same drain was also the primary source of copper. Other major sources of copper loading were drain SI-176 (a 30-in concrete pipe outfall entering 1,200 ft from the head of the waterway on the south shore) and drain SI-717 (under Pier 7). Drain SI-716 was the primary source of both lead and zinc. Drains SI-172 and SI-717 were also important sources of lead and zinc.

An investigation by Norton and Johnson (1985) during a storm event in 1984 indicated that drain SI-172 accounted for 80 to 90 percent of the total zinc, copper, and lead loading and 98 percent of the arsenic loading to the waterway. Ten drains were sampled during the investigation. Loading estimates by Tetra Tech and Norton and Johnson (1985) differ because Tetra Tech's loading calculations are based on all available data, while Norton and Johnson's loading calculations are based on a single event.

7.3.3.3 Source Identification--

Observed spatial distributions, along with the loading data presented above, implicate four sources as the major contributors of metals to Sitcum Waterway: 1) the Port of Tacoma ore docks, 2) drain SI-172 discharging to the northeast corner of the waterway, 3) drain SI-176 discharging midway along the south shore of the waterway, and 4) drain SI-717 discharging to the head of the waterway along the north shore. Each potential source is discussed individually below.

Port of Tacoma Ore Docks--Elevated concentrations of copper, lead, and zinc along the north shore cannot be accounted for by discharge from any storm drain system. Substantially higher concentrations of these contaminants were found in surficial sediments in the vicinity of Terminal 7 along the north shore of the waterway than in those along the south shore.

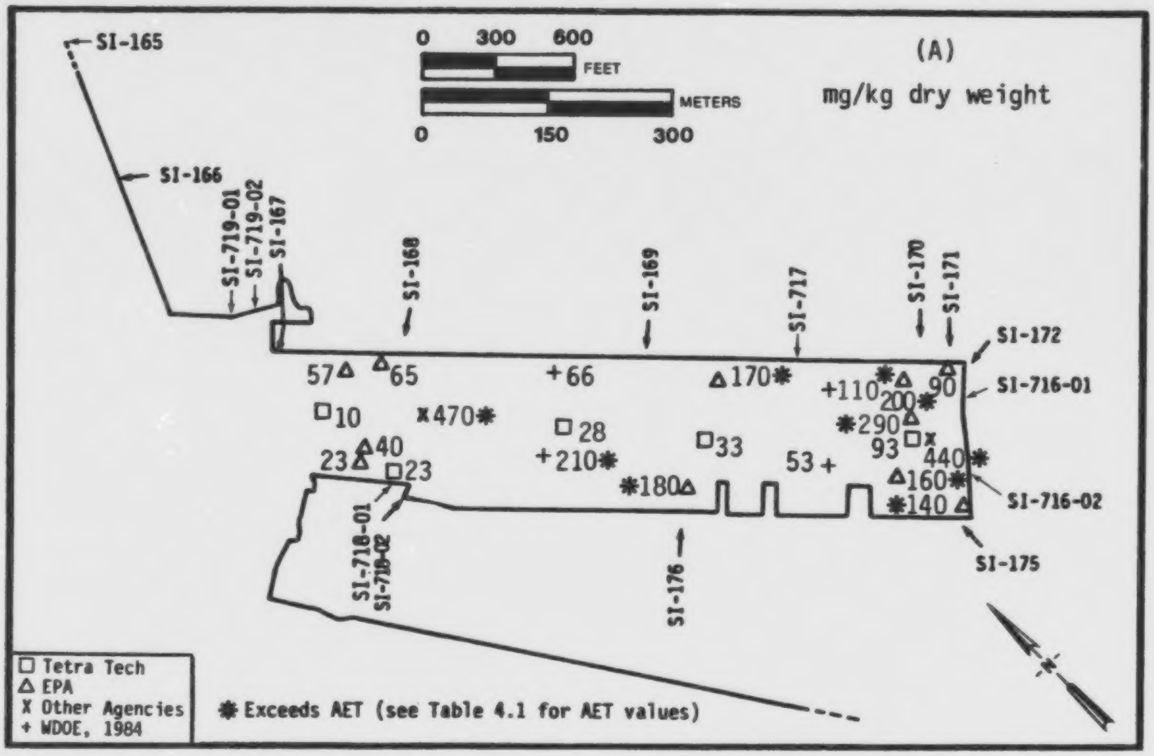


Figure 7.3.9

CONCENTRATIONS OF ARSENIC IN
SURFICIAL SEDIMENTS OF SITCUM WATERWAY

Table 7.3.2

CONCENTRATIONS OF ARSENIC AND METALS WITH DEPTH IN THE SEDIMENT

STATION SI-60, B02

	Contaminant			
	Copper	Lead	Zinc	Arsenic
Horizon 1 (0-0.10 m)	471	1,240	939	150
Horizon 2 (0.10-0.30 m)	669	1,670	1,100	210
Horizon 3 (0.30-0.41 m)	128	160	50	44

Concentrations in mg/kg dry weight

Table 7.3.3

ARSENIC: SUMMARY OF LOADINGS FROM DISCHARGES TO THE SITCUM WATERWAY

Drain #	Drain Name	Flow (MGD) (Avg. and Range) (# of Observations)	Period of Observations for Contaminant Concentrations	Concentration (ug/l) (Avg. and Range) (# of Observations)	Loading (lbs/day) (Avg. and Range)
SI-172	Storm Drain System	0.81 (0.11-5.2) (n=9)	3/29/82-6/29/84	264 (4.5-1,750) (n=10)	1.8 (.03-11.82)
SI-175	24-inch Concrete Pipe	0.088 (.09-.086) (n=2)	6/26/84	5.5 (1-10) (n=2)	0.0040 (.00073-.0073)
SI-176	30-inch Concrete Pipe	0.39 --- (n=1)	6/26/84	21 --- (n=1)	0.068
SP-716	PVC Pipe	0.044 --- (n=1)	6/26/84	9.5 --- (n=1)	0.0035
SI-717	Drain under Pier 7	0.56 --- (n=1)	6/26/84	12 --- (n=1)	0.056
SI-718	Bulkhead Drain	0.013 --- (n=1)	6/26/84	9 --- (n=1)	0.0098
SI-719	Concrete Drain Pipe	.053 --- (n=1)	6/26/84	5.5 --- (n=1)	0.0024

Table 7.3.4

COPPER: SUMMARY OF LOADINGS FROM DISCHARGES TO THE SITCUM WATERWAY

Drain #	Drain Name	Flow (MGD) (Avg. and Range) (# of Observations)	Period of Observations for Contaminant Concentrations	Concentration (ug/l) (Avg. and Range) (# of Observations)	Loading (lbs/day) (Avg. and Range)
SI-172	Storm Drain System	0.81 (0.11-5.2) (n=9)	3/29/82-6/29/84	84.5 (30-176) (n=6)	0.57 (.20-1.19)
SI-175	24-inch Concrete Pipe	0.088 (.09-.086) (n=2)	6/26/84	41 --- (n=1)	.030
SI-176	30-inch Concrete Pipe	0.39 --- (n=1)	6/26/84	118 --- (n=1)	0.38
SP-716	PVC Pipe	0.044 --- (n=1)	6/26/84	48 --- (n=1)	0.018
SI-717	Drain under Pier 7	0.56 --- (n=1)	6/26/84	78 --- (n=1)	0.36
SI-718	Bulkhead Drain	0.013 --- (n=1)	6/26/84	64 --- (n=1)	0.0069
SI-719	Concrete Drain Pipe	.053 --- (n=1)	6/26/84	61 --- (n=1)	0.027

Table 7.3.5

LEAD: SUMMARY OF LOADINGS FROM DISCHARGES TO THE SITCUM WATERWAY

Drain #	Drain Name	Flow (MGD) (Avg. and Range) (# of Observations)	Period of Observations for Contaminant Concentrations	Concentration (ug/l) (Avg. and Range) (# of Observations)	Loading (lbs/day) (Avg. and Range)
SI-172	Storm Drain System	0.81 (0.11-5.2) (n=9)	3/29/82-6/29/84	53.3 (12-199) (n=10)	0.36 (0.081-1.34)
SI-175	24-inch Concrete Pipe	0.088 (.09-.086) (n=2)	6/26/84	30 (20-40) (n=2)	0.022 (0.015-0.029)
SI-176	30-inch Concrete Pipe	0.39 --- (n=1)	6/26/84	479 --- (n=1)	1.56
SP-716	PVC Pipe	0.044 --- (n=1)	6/26/84	76 --- (n=1)	0.028
SI-717	Drain under Pier 7	0.56 --- (n=1)	6/26/84	193.5 --- (n=1)	0.90
SI-718	Bulkhead Drain	0.013 --- (n=1)	6/26/84	53 --- (n=1)	0.0057
SI-719	Concrete Drain Pipe	.053 --- (n=1)	6/26/84	191 --- (n=1)	0.084

Table 7.3.6

ZINC: SUMMARY OF LOADINGS FROM DISCHARGES TO THE SITCUM WATERWAY

Drain #	Drain Name	Flow (MGD) (Avg. and Range) (# of Observations)	Period of Observations for Contaminant Concentrations	Concentration (ug/l) (Avg. and Range) (# of Observations)	Loading (lbs/day) (Avg. and Range)
SI-172	Storm Drain System	0.81 (0.11-5.2) (n=9)	3/29/82-6/29/84	181.9 (60-553) (n=10)	1.2 (0.41-3.74)
SI-175	24-inch Concrete Pipe	0.088 (.09-.086) (n=2)	6/26/84	272.5 (155-390) (n=2)	0.20 (0.11-0.29)
SI-176	30-inch Concrete Pipe	0.39 --- (n=1)	6/26/84	537 --- (n=1)	1.75
SP-716	PVC Pipe	0.044 --- (n=1)	6/26/84	79 --- (n=1)	0.029
SI-717	Drain under Pier 7	0.56 --- (n=1)	6/26/84	262.5 --- (n=1)	1.2
SI-718	Bulkhead Drain	0.013 --- (n=1)	6/26/84	275 --- (n=1)	0.030
SI-719	Concrete Drain Pipe	.053 --- (n=1)	6/26/84	244 --- (n=1)	0.11

Terminal 7 has facilities for handling and bulk unloading of alumina, metal ores, and ore concentrates. Copper, lead, and zinc ores handled at Terminal 7 are probable sources of these contaminants in Sitcum Waterway. As noted by Norton and Johnson (1985), spillage occurs in the dock area in the process of unloading ore. It is the practice of the Port of Tacoma to sweep up material that can be recovered and to wash the remainder into the waterway.

Drain SI-172--From the available information, SI-172, the North Corner drain, appears to be a major source of metals to Sitcum Waterway. Two facts point to this conclusion. First, the highest concentrations of arsenic (288 mg/kg), copper (7,000 mg/kg), and zinc (3,200 mg/kg), and the second highest concentration of lead (1,900 mg/kg) in surficial sediments of the waterway were found intertidally at the outfall of the North Corner drain. Second, the North Corner drain contributed 93 percent of the quantified arsenic loading to the waterway, 41 percent of the copper, 12 percent of the lead, and 27 percent of the zinc. [These percentages are not consistent with those provided by Norton and Johnson (1985). Norton and Johnson used data from a single storm event in June, 1984, whereas the loadings shown herein are based on an average of 6 to 10 analyses of SI-172 effluent over several years.]

The watershed of the tideflats from which runoff would be discharged to Sitcum Waterway through SI-172 is shown in Figure 7.3.1. The area is bounded by East 11th Street, Lincoln Avenue, Port of Tacoma Road, and Milwaukee Way. This area is occupied by a number of small to moderate-sized industries, many of which could be contributors of the metals loading from SI-172. It is impossible to determine the ultimate sources of metals from this discharge with the available data.

Allied Chemical is the only industry within the SI-172 drainage area at which operations have resulted in known environmental contamination by trace metals. The firm produces aluminum sulfate and has historically disposed of wastes in on-site ponds. As a result of this practice, groundwater has become contaminated with sulfate (up to 14,000 mg/L), chromium (up to 0.55 mg/L), zinc (up to 2.3 mg/L), and aluminum (up to 2,300 mg/L) (Hart-Crowser and Associates 1983a,b). A slight elevation in lead concentrations beneath the waste ponds was indicated, although it is not among the primary waste constituents. No data are available for copper.

A recent groundwater study of the Allied Chemical site (Hart-Crowser and Associates 1983b) found that within an exploration depth of 10 m, both an upper and middle sand aquifer have become contaminated. Contaminants were reported to be migrating west and south of the site in the upper aquifer and north-northeast in the middle aquifer. This indicates that contamination in the upper aquifer may impact water and sediment quality in Sitcum Waterway, although there are insufficient data to adequately characterize off-site groundwater flow and determine the actual area of discharge. Hart-Crowser and Associates (1983b) suggested that, with the possible exception of zinc and aluminum, any other metals associated with the wastes would be immobilized by adsorption to soil particles and would not migrate far off-site.

Drain SI-176--This drain discharges surface water runoff midway along the south shore of Sitcum Waterway. This storm drain serves the 170-ac Sealand facility located on the south side of the waterway. Based on a single analysis, it contributes 53 percent of the quantified lead loading, 38 percent of the zinc, and 27 percent of the copper to Sitcum Waterway.

The source of metals within the drainage area of SI-176 is unknown. Metal ores have not been unloaded on this side of the waterway (Kucinski, G., 9 August 1985, personal communication). A potential source may be the leaching of metals from ASARCO slag that was used to riprap the southern shore. Source investigation may be necessary to determine the source of metals in discharge SI-176. Additional sampling also may be justified to confirm the significance of this source, since loading estimates were based on a single sampling event.

Drain SI-717--This drain discharges surface water runoff near the head of the waterway along the north shore. Based on a single analysis, it contributes 35 percent of the quantified copper loading, 30 percent of the lead, 27 percent of the zinc, and 3 percent of the arsenic to Sitcum Waterway. The origin of this discharge was not established during these investigations, although judging from its location, it may carry runoff from the Port's ore handling facilities on Terminal 7. Further efforts may be warranted to determine the source of the discharge and to better quantify its metals contribution.

Cascade Pole may also be a source of metals, although there was no evidence in the available data of elevated sediment contaminant concentrations attributable to this site. From 1936 to 1975, Cascade Pole was located near the head of the waterway on the north shore. This firm treated wood with pentachlorophenol, creosote, chrome, and arsenic and may have been a historical source of arsenic (in addition to other contaminants not identified to be of concern in Sitcum Waterway). There was no evidence of elevated arsenic concentrations in the area of the waterway nearest Cascade Pole that cannot be explained by arsenic input from the SI-172 storm drain.

7.3.3.4 Summary and Recommendations--

Four ongoing sources of copper, lead, zinc, and arsenic have been identified:

- The elevated metal concentrations along the north shore are believed to be a result of ore spillage from the Port of Tacoma ore docks. Copper, lead, and zinc ores are off-loaded at the facility and spillage is typically washed into the waterway.
- The North Corner storm drain (SI-172) is the major source of arsenic to Sitcum Waterway, contributing 93 percent of the total quantified loading. It is also a significant source of copper, lead, and zinc.

- Drain SI-176, which discharges along the south shore, is a source of copper, lead, and zinc. The source of metals to this drain has not been determined.

- Drain SI-717, which discharges along the north shore near the head of the waterway, is a source of copper, lead, and zinc. The source of metals to this drain has not been determined but may be associated with the Port's ore handling facilities.

Loadings of metals to Sitcum Waterway could be dramatically reduced if source control efforts were initiated to minimize or eliminate discharges from the ore docks and drains SI-172, SI-176, and SI-717. However, the metals already in the waterway sediments would be expected to remain there, except as moved or buried by sediment transport and deposition. There are no reliable estimates available by which to predict the rate of these processes.

Three recommendations can be made based on the results of the source identification efforts:

- Spillage of ore from the Port of Tacoma facilities on the north shore should be minimized or eliminated. Alternatives to washing spilled ore into the waterway should be investigated.

- Drain SI-172 serves a large area occupied by numerous small to moderate-sized industries. Since this drain contributes the vast majority of arsenic to the waterway, as well as significant quantities of other metals, the ultimate sources of metals within the drainage basin should be identified. The transportation route of the ore material should be investigated. Even if the sources cannot be identified, construction of settling basins or similar facilities could be used to reduce the particulate load and, therefore, the metals load of this discharge.

- The importance of drains SI-717 and SI-176 as sources of metals should be verified by additional sampling since the conclusions presented herein are based on a single analysis. If the drain is shown to be a major contributor of metals, then the source of these metals to the drain should be identified.

7.4 ST. PAUL WATERWAY

7.4.1 Introduction

St. Paul Waterway was created in stages from 1920 to the early 1930s (Dames and Moore 1982). Its basic outline extended to 11th Street in a 1923 chart of the tideflats area (Hart-Crowser and Associates undated). A 1946 chart indicates that the inner portion of the waterway was used for log rafts and booms and was navigable to shallow draft boats (Hart-Crowser and Associates undated). It is likely that this part of the waterway remained tidal and was never dredged (Stargell, W., personal communication). In the early 1960s, the head of the waterway was filled to create the current configuration, which is about half its former size. Fill material is believed to have come from the Army Corps of Engineers dredging of the Puyallup River (Stargell, W., personal communication) and may have included slash and sawdust from Champion International (Dames and Moore 1982).

Champion International (formerly St. Regis Paper Company) occupies the land surrounding St. Paul Waterway (Figure 7.4.1), including the area at the head of the waterway filled in the 1960s. Current operations consist of a stud mill, pulp and paper mill, bag manufacturing plant, distribution yard, log storage yards, and an industrial supply section(Stargell, W., personal communication). In the past, operations included a veneer plant and a factory constructing panelized structures and modular homes (Ruckelshaus unpublished). Paxport Mills manufactures cedar fencing and alder paneling at their sawmill on the waterway's west peninsula. The mill has operated since the late 1960s.

Land use surrounding St. Paul Waterway has been restricted to the forest products industry. The St. Paul and Tacoma Lumber Company was the first industry located near the St. Paul Waterway and the first constructed in the tideflats area. The mill opened in 1889 on "The Boot," a tideflat area now bounded by Wheeler-Osgood Waterway, the Puyallup River, East 11th Street, and Puyallup Avenue (Morgan and Morgan 1984). The St. Regis paper company expanded its operation on the St. Paul waterfront from its original location along the Puyallup River when it bought land from the St. Paul and Tacoma Lumber Company in 1940. In the 1930s and 1940s, Donald W. Lyle operated a plywood cutting operation and log bay along St. Paul Waterway (Ruckelshaus unpublished). In 1959, St. Regis (now Champion International) acquired the St. Paul and Tacoma Lumber Company (Stargell, W., personal communication). Champion International is currently the only industry along St. Paul Waterway.

Discharges to St. Paul Waterway are shown in Figure 7.4.1. Champion International has the only NPDES-permitted discharge (SP-189), located at the end of the east peninsula separating the St. Paul Waterway and Puyallup River via PU-190. Champion continues to use this outfall periodically during plant upsets or treatment malfunctions. This discharge has been in use since 1970. Earlier, Champion (then St. Regis) discharged to the Puyallup River via PU-190. Champion continues to use this outfall periodically as a bypass during plant upsets or treatment malfunctions. The current

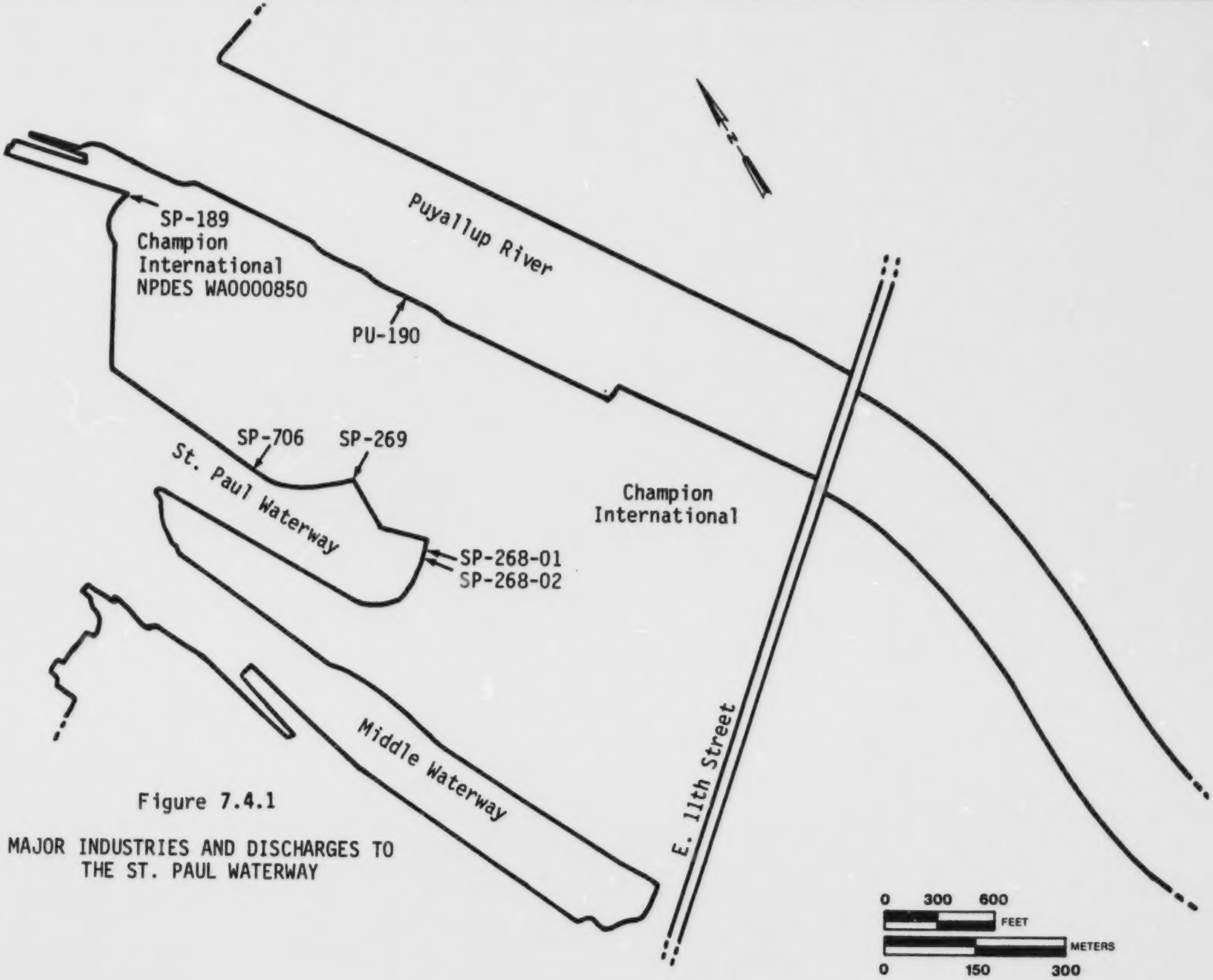


Figure 7.4.1

MAJOR INDUSTRIES AND DISCHARGES TO THE ST. PAUL WATERWAY discharge has permit limits on BOD, pH, and suspended solids. Champion International is also required to report discharge temperature and total production. Two 24-in storm drains (SP-268-01 and SP-268-02) also discharge to the south end of the waterway.

The location of sediment chemistry stations in St. Paul Waterway, including those sampled as part of the Superfund investigation and all historical sampling sites, are shown in Figure 7.4.2. Stations designated to be of concern in these investigations are SP-13, SP-14, SP-15, and SP-16 located at the mouth of the St. Paul Waterway and in Commencement Bay north of the waterway. Contaminants or contaminant groups designated to be of preliminary concern at these stations include

Organic Compounds	Inorganic Substances
Organic enrichment	
Alkylated phenols	Copper
Methoxyphenols	
1-Methyl(2-methylethyl)benzene	
Naphthalene	
Methylnaphthalene	

The spatial distributions, known loadings, and potential sources of these compounds are discussed below. Chloroform was detected at elevated concentrations in a 1981 WDOE Class II survey of the Champion International effluent and receiving waters (Yake 1982b). This volatile compound was undetected in all sediment samples analyzed from St. Paul Waterway at a detection limit of 10 ug/kg dry weight. Chloroform was also undetected (5 ug/kg wet weight) in four English sole muscle tissue samples from St. Paul Waterway. Therefore, chloroform is not a chemical of concern with respect to sediment contamination or bioaccumulation.

Concentrations of the preliminary contaminants of concern listed above were later determined to exceed toxicity or benthic AET in sediments from at least one station in St. Paul Waterway. The one exception was copper, which was of concern because of its significant bioaccumulation in English sole muscle tissue. Copper concentrations did not exceed toxicity or benthic AET in any surface or subsurface sediment sample from St. Paul Waterway. Other substances that were present above AET at a single station only (Priority 3 chemicals; see Table 6.14 in Section 6) but for which sources have not yet been evaluated include:

Substance	Station Where AET Exceeded
Phenol	SP-14
Benzyl alcohol	SP-13, SP-14, SP-16
Nickel	SP-14

Additional tentatively identified chemicals present above AET include retene (Station SP-16 only), two diterpenoid hydrocarbons (Stations SP-14

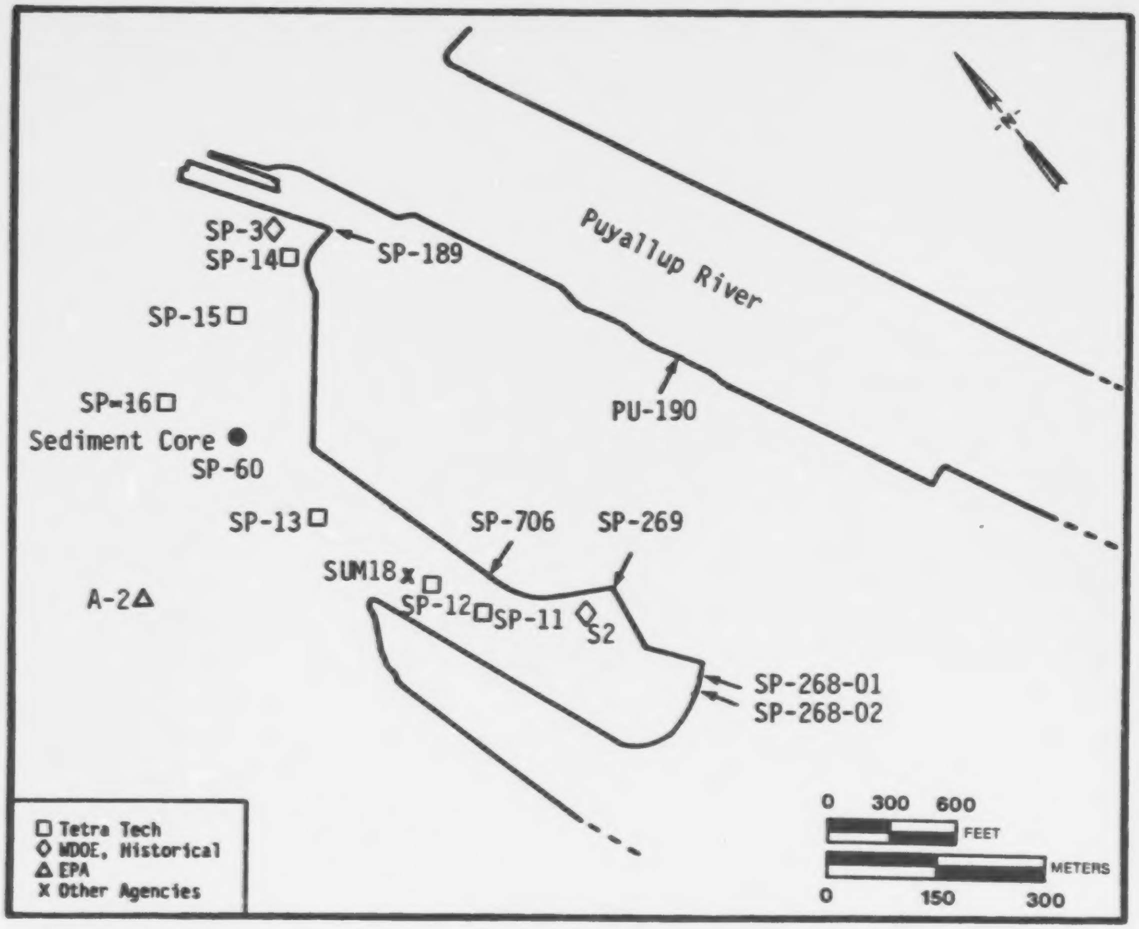


Figure 7.4.2

SURFICIAL SEDIMENT STATIONS AND SEDIMENT CORE LOCATIONS
FROM ALL STUDIES IN THE ST. PAUL WATERWAY

and SP-15), and biphenyl (Station SP-14 only). Total volatile solids were also above AET at Station SP-14 only. These substances are not discussed further.

Average mass flux estimates were calculated only for copper and naphthalene in St. Paul Waterway. Source data for other contaminants were insufficient for analysis. Mass flux estimates for copper and naphthalene were evaluated using average concentrations of these contaminants in sediments from all present and historical stations according to the procedures and criteria outlined in Section 2.12.3.2. When calculating the source-derived mass flux, potential copper loadings from the Puyallup River (Table 7.4.3) were excluded because of uncertainties concerning the appropriate dilution factor. Even without this loading component, the source-derived mass flux for copper still exceeds the sediment concentration-derived mass flux by an order of magnitude. The corresponding source-derived mass flux for naphthalene is less than the concentration-derived mass flux by an order of magnitude. According to the uncertainty criteria for this analysis, no data gaps were indicated in accounting for major sources of naphthalene or copper, even when contributions from the Puyallup River are ignored.

7.4.2 Spatial Distribution

Spatial distributions of contaminants of concern in surficial sediments of St. Paul Waterway are shown in Figures 7.4.3-7.4.9. All contaminants showed similar concentration gradients, with the highest concentration (dry-weight basis) at Station SP-14. Contaminant concentrations at this station were 1.5 to 30 times greater on a dry-weight basis than those at any other station in St. Paul Waterway. The proximity of discharge SP-189 to this area of elevated contaminant concentrations suggests that SP-189 is the major source of the contaminants.

Contaminated sediments at Station SP-14 off discharge SP-189 contained high levels of TOC (16 percent). Similar levels of organic enrichment were not found at any other station in St. Paul Waterway (Figure 7.4.3). This TOC distribution indicated dilution of sediments beyond the immediate vicinity of Station SP-14 by relatively organic-poor material from other sources (e.g., the Puyallup River). Although the lowest concentrations of organic carbon in St. Paul Waterway were found at Stations SP-15 and SP-16 (TOC +2 percent) adjacent to Station SP-14, these sediments remained substantially contaminated by organic compounds and metals on a dry-weight basis.

After normalization to organic carbon among these stations, 4-methylphenol concentrations steadily decreased with distance from Station SP-14 (Figure 7.4.4). This spatial pattern strongly suggests a single source of 4-methylphenol originating at discharge SP-189, the main outfall of Champion International. Concentrations of other organic contaminants normalized to TOC (Figures 7.4.5-7.4.8) did not show a similar gradient, but the highest concentrations (TOC basis) of 2-methoxyphenol and 1-methyl(2-methylethyl)benzene were still found in the area defined by Stations SP-14, SP-15, and SP-16.

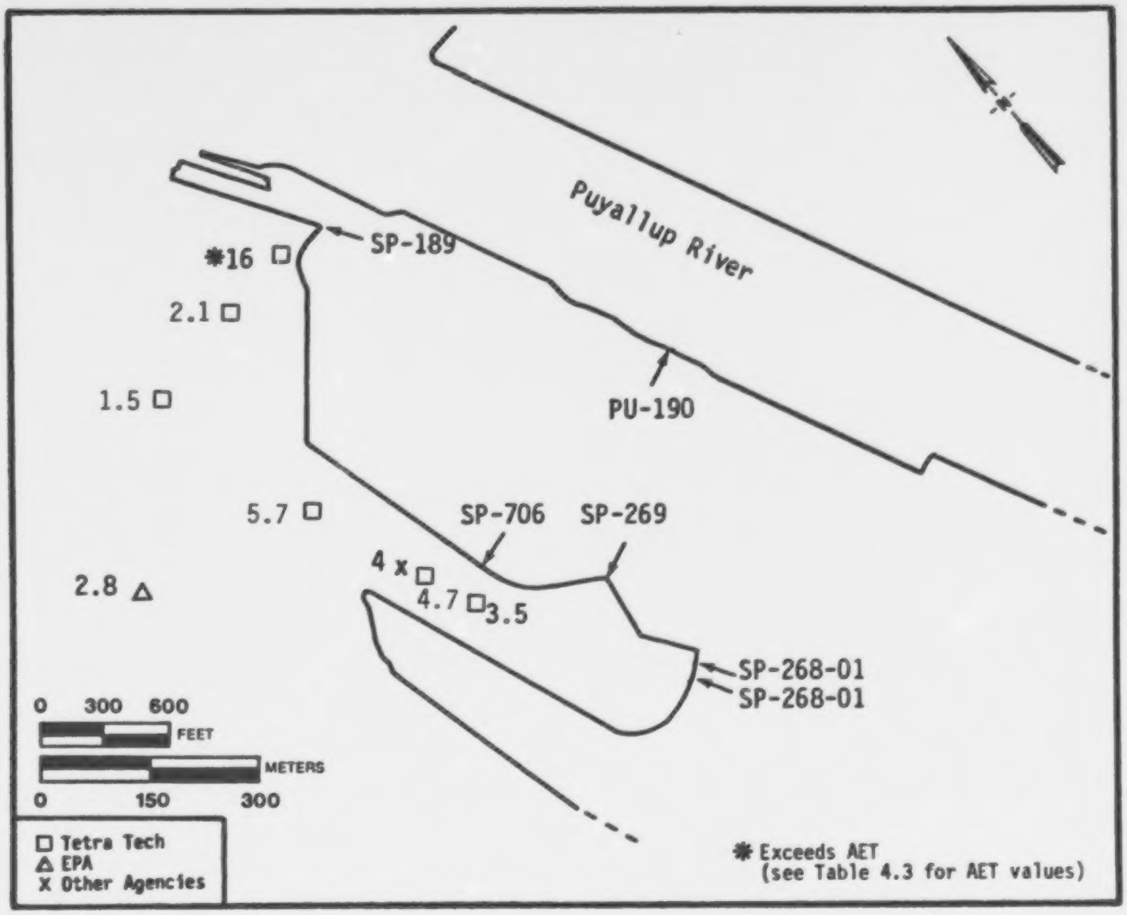


Figure 7.4.3

CONCENTRATIONS OF TOTAL ORGANIC CARBON (%)
IN THE SURFICIAL SEDIMENTS OF THE
ST. PAUL WATERWAY

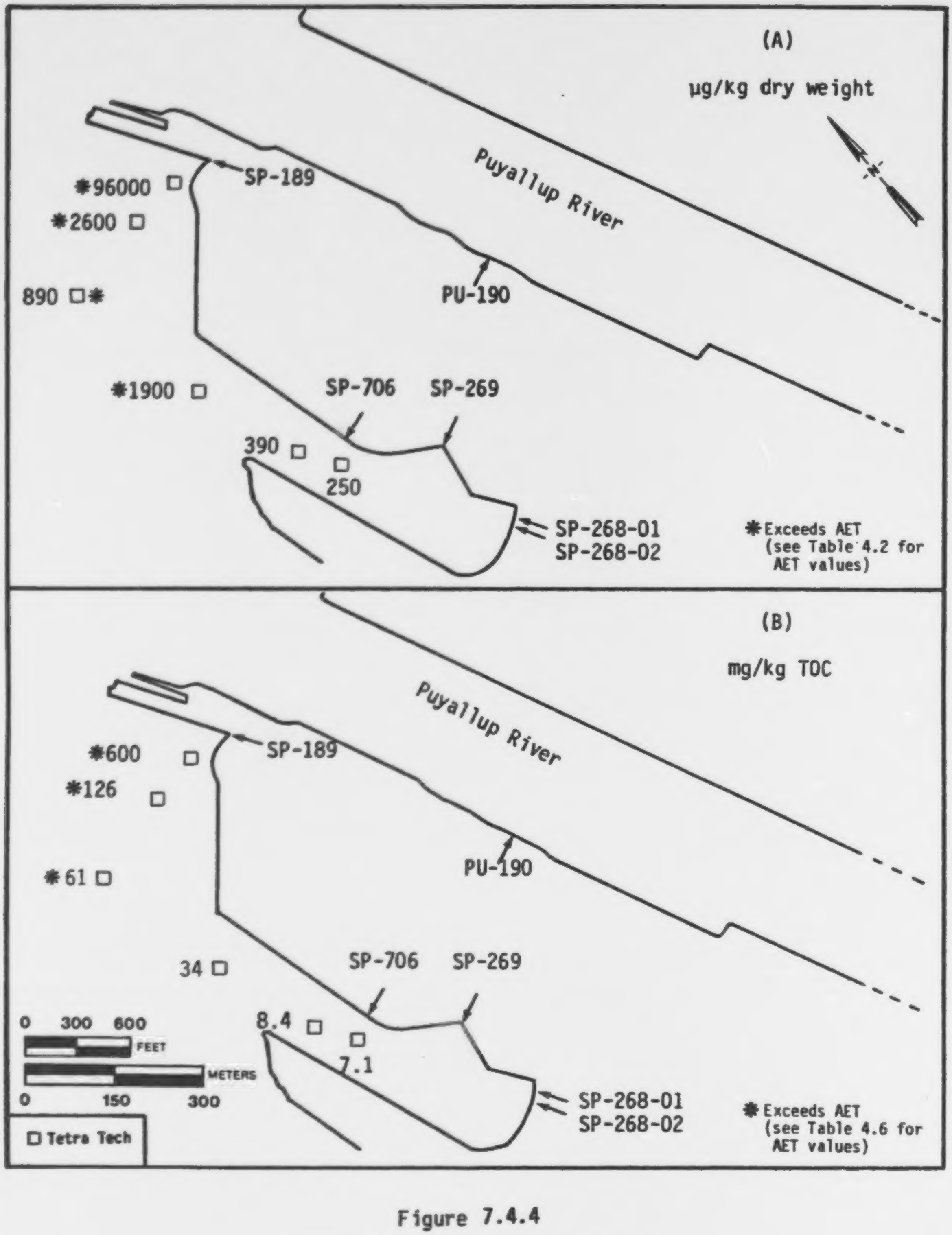


Figure 7.4.4

CONCENTRATIONS OF 4-METHYLPHENOL
IN THE SURFICIAL SEDIMENTS OF THE
ST. PAUL WATERWAY

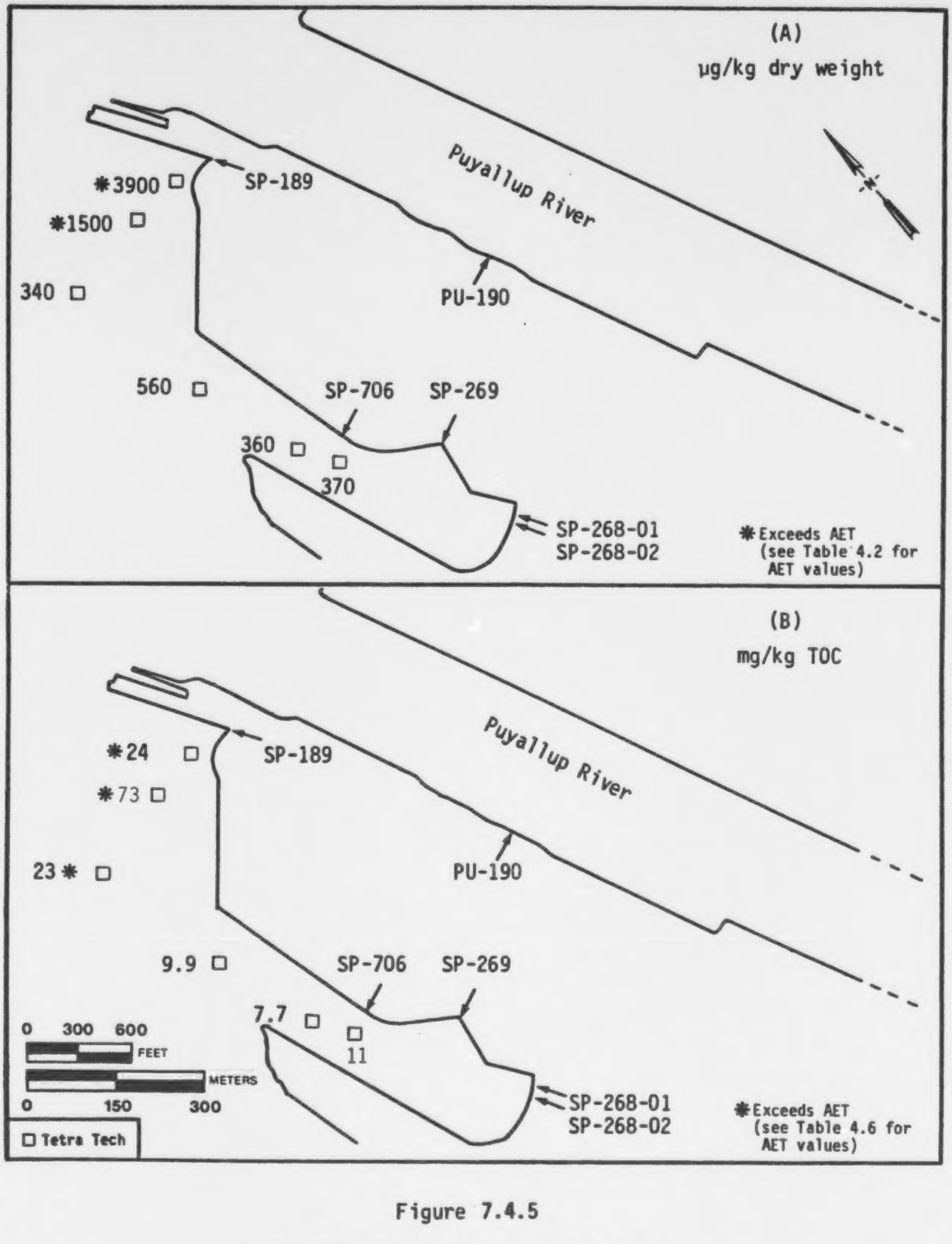


Figure 7.4.5

CONCENTRATIONS OF 2-METHOXYPHENOL
IN THE SURFICIAL SEDIMENTS OF THE
ST. PAUL WATERWAY

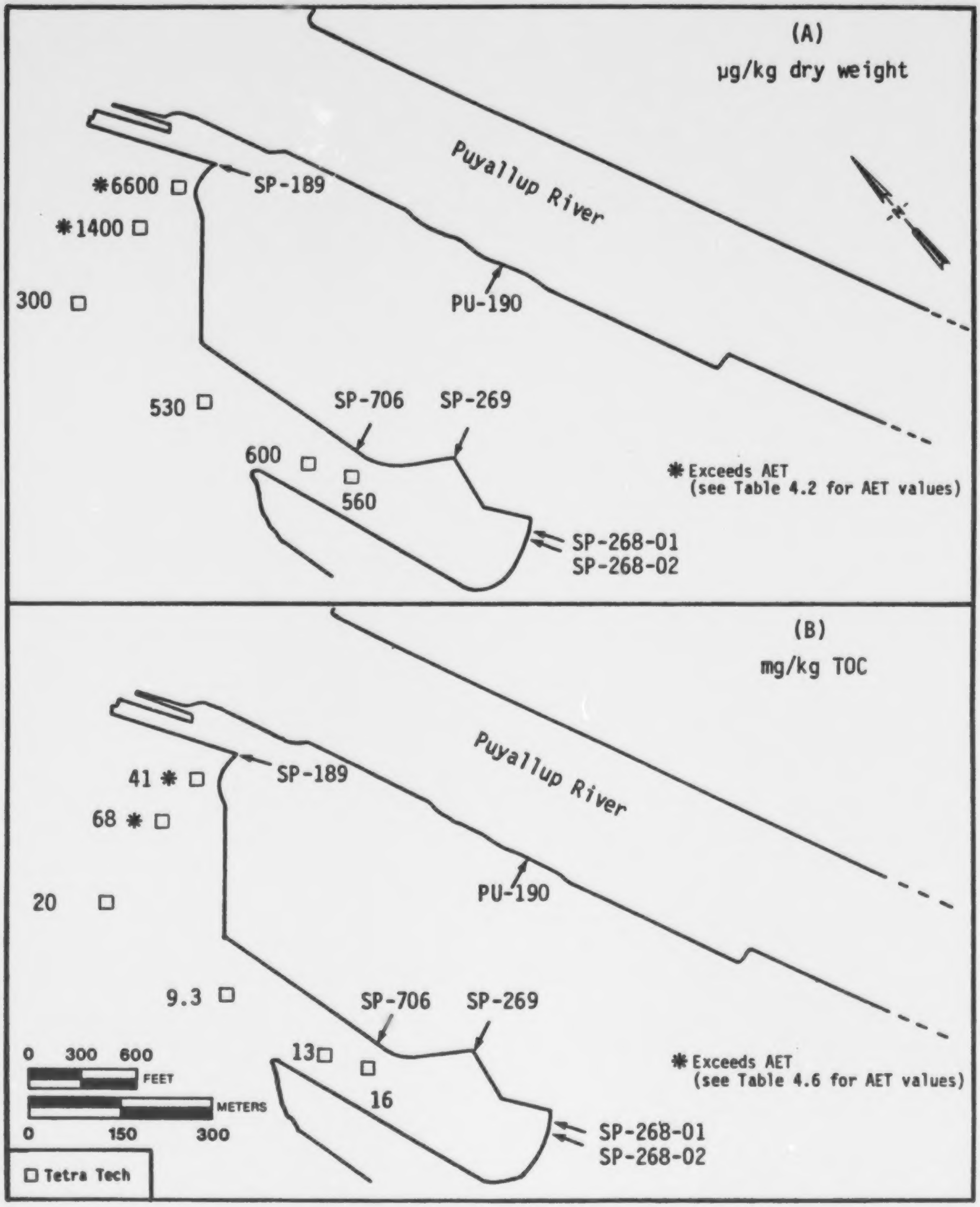


Figure 7.4.6

CONCENTRATIONS OF 1-methyl-2-(1-methylethyl)benzene
IN THE SURFICIAL SEDIMENTS OF THE
ST. PAUL WATERWAY

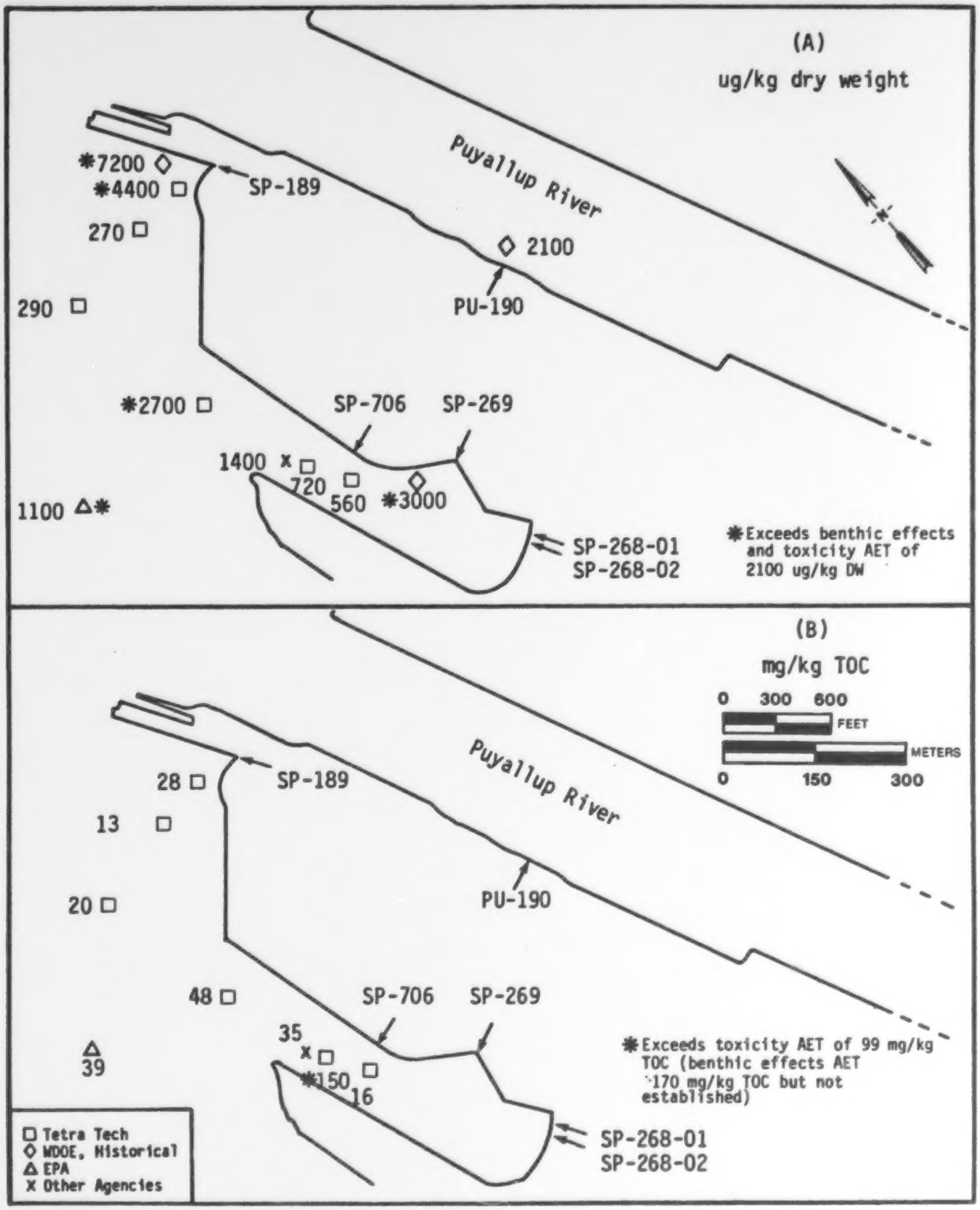


Figure 7.4.7

CONCENTRATIONS OF NAPHTHALENE
IN THE SURFICIAL SEDIMENTS OF THE
ST. PAUL WATERWAY

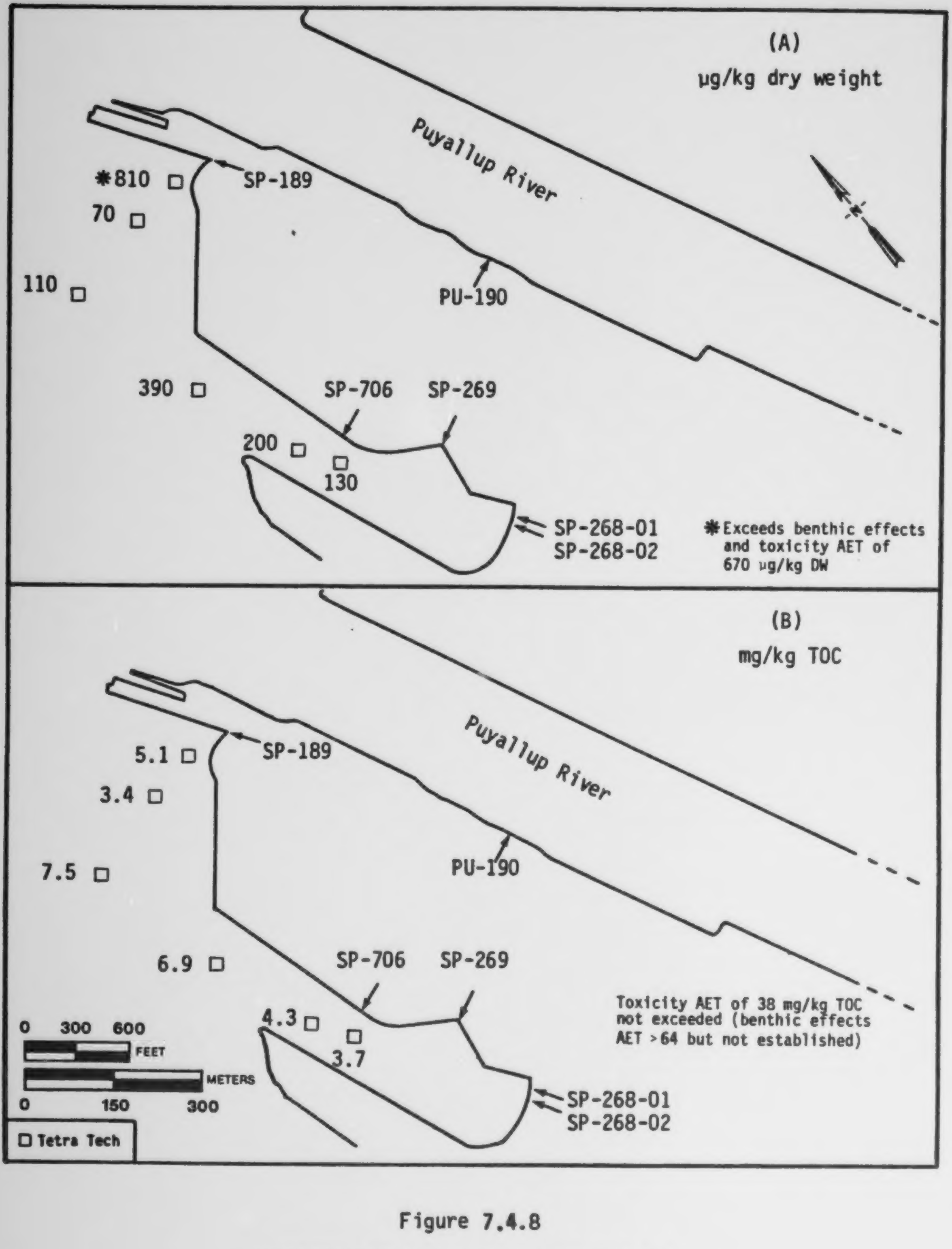


Figure 7.4.8

CONCENTRATIONS OF 2-METHYLNAPHTHALENE
IN THE SURFICIAL SEDIMENTS OF THE
ST. PAUL WATERWAY

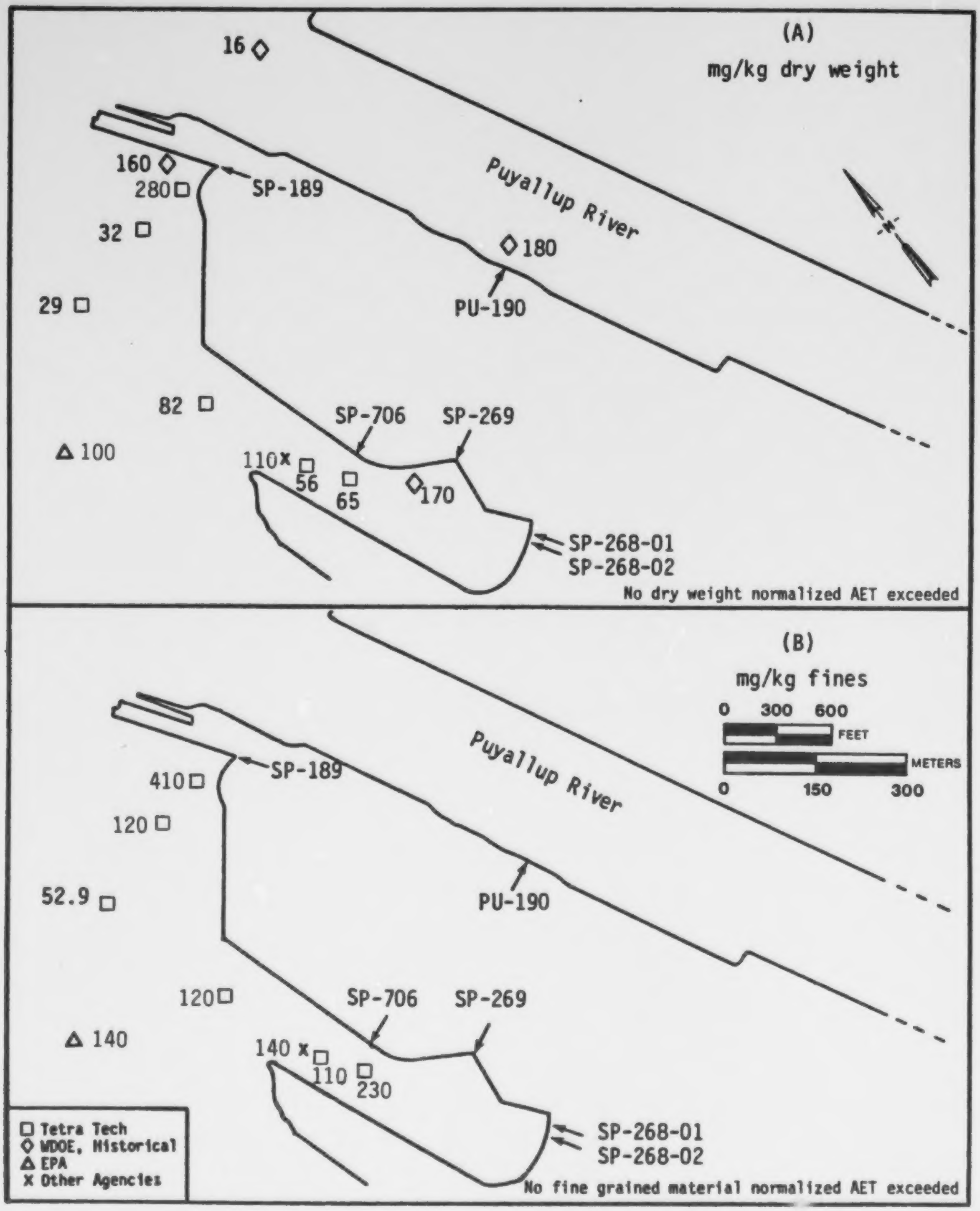


Figure 7.4.9

CONCENTRATIONS OF COPPER IN THE SURFICIAL SEDIMENTS
OF THE ST. PAUL WATERWAY

Concentrations of naphthalene normalized to organic carbon were highest in sediments from Station SP-12 near discharge SP-706 (Figure 7.4.7), while normalized concentrations of 2-methylnapthalene (a related hydrocarbon) were similar among all stations in St. Paul Waterway (Figure 7.4.8). This pattern differed from that of 4-methylphenol normalized to organic carbon and indicated that these hydrocarbons likely derive from different sources in St. Paul Waterway. At least two sources of copper are also indicated in St. Paul Waterway because high concentrations of copper (dry-weight basis) were found at Station SP-14 and at a well-removed historical station near the head of the waterway (Figure 7.4.9). Although grain size data were not available for all historical stations, copper concentrations normalized to percent fine-grained material also showed consistent evidence of at least two sources of copper (Figure 7.4.9). No samples have been collected directly at the head of the waterway to help determine if drains or runoff in that area are potential contributors of copper.

Only a single sediment core sample was available from St. Paul Waterway. In general, contaminant concentrations were similar in both the upper and lower horizons (Table 7.4.1). For some of the contaminants of concern (e.g., alkylated phenols), the similarity of concentrations throughout the core may reflect mobility in interstitial water, a relatively constant pattern of historical contaminant input, or constant in situ production throughout the core. For relatively insoluble contaminants (e.g., copper), the similarity of concentrations throughout the core suggests input at an approximately constant rate over the depositional period sampled by the core.

7.4.3 Loading Estimates

Loadings of the contaminants of concern from all known discharges to St. Paul Waterway are discussed below. The Puyallup River is treated as a discharge because of the potential effect of riverine loading on sediment quality in the adjacent St. Paul Waterway. Because of dilution and dispersion of the Puyallup River plume, only a small portion of the river's total contaminant load could affect sediment quality in St. Paul Waterway.

7.4.3.1 Organic Enrichment--

In order to identify potential sources of the organic material in the area of concern, available data on BOD, COD, and total suspended solids (TSS) in discharges to St. Paul Waterway were compiled, as summarized in Table 7.4.2. The Puyallup River is a major contributor of BOD, COD, and TSS to Commencement Bay. Although the portion of this loading reaching St. Paul Waterway is unknown, it is believed to be small. The Champion International main outfall (SP-189) is the other discharge in the area of concern known to be a significant source of organic matter.

7.4.3.2 Alkylated Phenols--

Analyses have not been done for 2-methyl or 4-methylphenol in the Puyallup River or in any discharge to St. Paul Waterway. On eight occasions,

Table 7.4.1

CONCENTRATION OF THE CONTAMINANTS OF CONCERN WITH DEPTH IN THE SEDIMENT

STATION SP-60, B01

Contaminant	Horizon 1[a] (0-0.13 m)	Horizon 2[a] 0.13-0.30 m)
2-methylphenol	91[b]	89[b]
4-methylphenol	3,900[b]	3,900[b]
Naphthalene	1,490	2,010
2-methylnaphthalene	210	710[b]
Copper	73	84
Total organic carbon	8.3%	11.8%

No data available for methoxyphenols or 1-methyl(2-methylethyl)benzene.

---

[a] Concentrations given as ug/kg dry weight for organic compounds, mg/kg dry weight for copper.

[b] Concentration exceeds toxicity or benthic AET.

Table 7.4.2

BOD, COD, AND TOTAL SUSPENDED SOLIDS: SUMMARY OF LOADINGS FROM DISCHARGES TO THE ST. PAUL WATERWAY AND FROM THE PUYALLUP RIVER[a]

Drain #	Drain Name	Flow (MGD) (Avg. and Range) (# of Observations)	Period of Observations for Contaminant Concentrations	Concentration (ug/l) (Avg. and Range) (# of Observations)	Loading (lbs/day) (Avg. and Range)
			BOD_5[a]		
PU-000	Lower Puyallup River Mouth to Clear Creek	4044.2 (1,157-12,215) (n=4)	8/25/81	11,000[c] (6,000-18,000) (n=3)	370,000 (200,000-610,000)
SP-189	Champion International Main Outfall	32.2 --- (n=1)	8/11/81	26,000 --- (n=1)	7,000
			COD[b]		
PU-000	Lower Puyallup River Mouth to Clear Creek	4044.2 (1,157-12,215) (n=4)	8/25/81-2/16/82	26,000[c] (9,000-40,000) (n=5)	880,000 (300,000-1,300,000)
SP-189	Champion International Main Outfall	32.2 --- (n=1)	8/11/81	500,000 --- (n=1)	130,000
			TOTAL SUSPENDED SOLIDS[b]		
PU-000	Lower Puyallup River Mouth to Clear Creek	4044.2 (1,157-12,215) (n=4)	8/25/81-2/16/82	380,000 (270,000-600,000) (n=5)	12,000,000 (9,100,000-20,000,000)
SP-189	Champion International Main Outfall	32.2 --- (n=1)	8/11/81	100,000 --- (n=1)	27,000
SP-268-01	St. Paul Storm Drain	0.129 (0.026-0.232) (n=2)	6/29/84	260,000 --- (n=1)	280
SP-268-02	St. Paul Storm Drain	0.080 (0.043-0.116) (n=2)	12/12/83-6/29/84	34,000 (16,000-52,000) (n=2)	23 (11-35)

[a] The Puyallup River loading represent total loading to Commencement Bay; loading to St. Paul Waterway considerably lower.

[b] From data in project data base only.

[c] Excluding WDOE Station 4 sampled 8/25/81 at high slack tide (Johnson and Prescott 1982b). This sample was collected <50 m upriver from Tacoma Central STP outfall and is more representative of STP effluent than actual river water.

the Puyallup River has been analyzed for 2,4-dimethylphenol. The compound was not detected at a detection limit of 10 ug/L.

7.4.3.3 Naphthalene--

Naphthalene loading from discharges to St. Paul Waterway is summarized in Table 7.4.3. The Champion International main outfall was the major contributor (1.2 lb/day), based on a single analysis of their discharge during the Class II survey (Yake 1982b). Naphthalene has not been detected in the Puyallup River (at a 10 ug/L detection limit), with the exception of a single sample taken within 50 m of the Tacoma Central sewage treatment plant (Johnson and Prescott 1982b). Based on the contaminant concentrations in this sample relative to other river samples, the sample was probably more representative of the treatment plant effluent rather than of Puyallup River water which could impact St. Paul Waterway.

7.4.3.4 Methoxyphenols, 1-Methyl(2-methylethyl)benzene, and Methylnaphthalene--

No analyses have been done for these compounds in the Puyallup River or in any discharge to St. Paul Waterway.

7.4.3.5 Copper--

Copper loadings from the Puyallup River and in discharges to St. Paul Waterway are summarized in Table 7.4.3. The Champion International main outfall effluent had the highest copper concentration of the known discharges, although the Puyallup River was a greater source of mass loadings to Commencement Bay because of the high flow volume of the river.

7.4.4 Source Identification

The highest concentrations (dry-weight basis) of all preliminary contaminants of concern were found at stations adjacent to the main outfall of Champion International (SP-189). Discharges from the main outfall of Champion International are therefore implicated as a major route by which contaminants reach St. Paul Waterway. Some contaminants (i.e., copper and hydrocarbons) may have additional sources elsewhere in the waterway.

The Champion International facility, recently purchased from St. Regis Paper Company, is a softwood, kraft pulp and paper mill. Kraft pulping involves the use of sodium hydroxide and sodium sulfide to dissolve lignin from the wood so that the cellulose fibers can be separated. The facility produces unbleached kraft linerboard, unbleached kraft paper, bleached paper, and bleached market pulp. Prior to 1970, untreated plant effluent was discharged to the Puyallup River through discharge PU-190 shown in Figure 7.4.1. In late 1970, primary clarification was initiated and the discharge was routed to its present location. Secondary treatment began in 1977. Wastewater is presently treated by primary clarification, pure oxygen activated sludge, and secondary clarification.

Table 7.4.3

NAPHTHALENE AND COPPER: SUMMARY OF LOADINGS FROM DISCHARGES TO THE ST. PAUL WATERWAY AND FROM THE PUYALLUP RIVER[a]

Drain #	Drain Name	Flow (MGD) (Avg. and Range) (# of Observations)	Period of Observations for Contaminant Concentrations	Concentration (ug/l) (Avg. and Range) (# of Observations)	Loading (lbs/day) (Avg. and Range)
			NAPHTHALENE		
SP-189	Champion International Main Outfall	32.2 --- (n=1)	8/11/81	4.4 --- (n=1)	1.2
SP-268-01	St. Paul Storm Drain	0.129 (0.026-0.232) (n=2)	9/14/81	0.4 --- (n=1)	0.00043
			COPPER		
PU-000	Lower Puyallup River Mouth to Clear Creek	4044.2 (1,157-12,215) (n=4)	7/28/81-2/16/82	<16[b] (9-20) (n=8)	<540 (304-675)
SP-189	Champion International Main Outfall	32.2 --- (n=1)	8/11/81	100 --- (n=1)	27
SP-268-01	St. Paul Storm Drain	0.129 (0.026-0.232) (n=2)	9/14/81	10 --- (n=1)	0.01
SP-268-02	St. Paul Storm Drain	0.080 (0.043-0.116) (n=2)	9/14/81	39[c] (26-60) (n=3)	0.026 (0.017-0.040)
SP-269	Ten-inch Corrugated Pipe	0.012 --- (n=1)	8/12/81	20 --- (n=1)	0.0020

[a] The Puyallup River loadings represent total loading to Commencement Bay; loading to St. Paul Waterway considerably lower.

[b] Excluding WDOE Station 4 sampled 8/25/81 at high slack tide (Johnson and Prescott 1982b). This sample was collected <50 m upriver from Tacoma Central STP outfall and is more representative of STP effluent than actual river water.

[c] Concentration corrected for contribution of blank.

As discussed in Section 7.4.3, only three of the seven preliminary contaminants or contaminant groups of concern have been detected in the Champion International effluent (naphthalene, copper, BOD). The effluent has not been analyzed for the other preliminary compounds of concern, but they could be associated with effluent from a pulp and paper mill. Each is discussed below with regard to known or potential presence in the Champion International effluent.

Chloroform was detected at elevated concentrations in 1981 analyses (Johnson and Prescott 1982c) of the plant effluent and receiving water. Chloroform was undetected at 10 ug/kg dry weight in samples from the three sediment stations analyzed for chloroform during the remedial investigation. These stations included Station SP-14 directly off the main outfall.

7.4.4.1 Organic Enrichment--

Pulp and paper mills have traditionally been of concern in water pollution abatement programs because of their discharge of suspended solids and oxygen-consuming materials. Activated sludge digestion and secondary clarification are designed to reduce the BOD/COD content of the Champion International effluent. However, even with this treatment, the outfall contributes 7,000 lb/day BOD and 130,000 lb/day COD. BOD limits of 7,300 lb/day daily average and 14,400 lb/day daily maximum are included in the firm's NPDES permit. Therefore, it is not surprising that the marine sediments near the outfall are organically enriched.

7.4.4.2 Alkylated Phenols--

2-Methylphenol (unidentified isomer), produced by cleavage of the lignin molecule, is frequently found in pulp mill effluents (LaFleur, L., personal communication). Although 4-methylphenol (p-cresol) has been reported as a constituent in pulp mill effluent (Nestmann et al. 1980), its presence is not typical. However, it is possible that 4-methylphenol is produced by anaerobic microbial breakdown of lignin.

Sediments in the vicinity of the Champion International outfall contained concentrations (dry weight) of 4-methylphenol that were two orders of magnitude greater than those from any other site in the nearshore/tideflats area. 2-Methylphenol was undetected in the sediments nearest the outfall. Therefore, alkylated phenols in the area of concern may originate from in situ microbial degradation of pulp processing wastes discharged from the Champion International outfall.

The degradation of wood chip debris in sediments is a possible source of alkylated phenols. The presence of wood or woody material in Commencement Bay sediments was checked through a review of grain size records for samples collected in March, 1984. Wood debris was noted in surface sediments from 89 stations that contained measurable quantities of 4-methylphenol. This group of stations included Stations SP-14 and SP-15 near the main outfall of Champion International. 4-Methylphenol was undetected at 10 ug/kg (dry weight) in sediments from an additional nine stations where wood debris was also noted (including two stations from Carr Inlet). Finally, 4-methylphenol was found at an average value of 170 ug/kg (maximum 890 ug/kg dry weight at Station SP-16) in sediments from 16 stations where no wood debris was reported in the grain size analyses. Although wood content could only be qualitatively estimated, there was no obvious correlation in the amount of wood debris suggested by grain size records and the concentration of 4-methylphenol in any of the sediment samples evaluated.

Degradation of wood debris (as opposed to pulping wastes contributed by effluents) is unlikely to account for the 96,000 ug/kg dry weight concentration observed in sediment from Station SP-14 off the main outfall of Champion International. Considerable wood debris was noted in sediment from Station CI-16 in Wheeler-Osgood Waterway. In fact, sediment coring in Wheeler-Osgood Waterway was difficult because of wood debris. The maximum concentration of 4-methylphenol in this organically enriched, anoxic basin was 1,200 ug/kg, approximately one percent of the concentration observed at Station SP-14. Other potential sources besides wood debris were also identified in Wheeler-Osgood Waterway. It was concluded that degradation of wood debris may contribute a portion of the 4-methylphenol observed in some sediments. Other processes (i.e., the direct discharge of 4-methylphenol or degradation of some effluent component) appear to be of greater importance in St. Paul Waterway.

7.4.4.3 Methoxyphenols--

2-Methoxyphenol (guaiacol) is a major constituent in pulp mill effluents, because lignin consists of numerous propylguaiacol building blocks and guaiacol is one of the major products of lignin breakdown (Fox 1977). Of 43 constituents of pulp mill effluent identified by Nestmann et al. (1980), 2-methoxyphenol was present in the greatest concentrations (3 mg/L). It was also one of 16 major components identified by Fox (1977) from a pulp and paper mill on Lake Superior. No analyses were reported for this compound in the Champion International effluent. Since the compound is characteristic of the pulp and paper production, it is probable that it is entering the waterway via the main outfall.

7.4.4.4 1-Methyl(2-methylethyl)benzene--

1-Methyl-2-(methylethyl)benzene (tentative identification; commonly known as p-cymene) is a common component of sulfite mill waste liquors and has also been identified in the effluent from a kraft mill (Rogers et al. 1982). 1-Methyl-2-(methylethyl)benzene, an alkylated benzene, is formed by the dehydration of monocyclic terpenes. These terpenes can be made from turpentine or obtained as a by-product from sulfite digestion of spruce pulp (Hawley 1981). Neither Champion International nor St. Regis has employed sulfite digestion in pulp and paper production. Alkylated benzenes derive from numerous sources not restricted to the pulp and paper industry. However, given the association of alkylated benzenes with the pulp and paper industry, and the high concentration of compounds observed in sediments near the Champioin International outfall, this class of compounds is probably present in the Champion International effluent. An alkylated benzene isomer has also been tentatively identified in the sediments near the plant's pre-1970 outfall on the Puyallup River (Yake 1982b).

7.4.4.5 Naphthalene and 2-Methylnaphthalene--

Naphthalene and methylnaphthalenes are occasionally seen as trace constituents in pulp and paper mill effluents, although they are usually not typical or major components (Wallin and Condren 1981). The Champion International effluent has been found to contain 4.4 ug/L naphthalene (Yake 1982b). Regulatory limits for naphthalene concentrations that induce chronic effects on saltwater organisms have not been established. The saltwater criterion for acute effects is 2,350 ug/L. The origin of naphthalene in the Champion International waste stream is not known. The compound is used as a fungicide (Hawley 1981) and may be used in small quantities in paper manufacturing.

7.4.4.6 Copper--

The Champion International effluent is a known source of copper, contributing 27 lb/day to Commencement Bay and St. Paul Waterway (Table 7.4.2). Water samples taken in Commencement Bay near the plant outfall contained 47 ug/L copper, twice the U.S. EPA maximum allowable concentration for saltwater (Johnson and Prescott 1982c). Copper is not a typical constituent of pulp and paper mill effluent. It is not clear why the metal is present in significant quantities in the Champion International effluent, although the NPDES permit recently issued to Champion International requires the firm to perform in-plant testing to determine the copper source. The WDOE is currently investigating the possibility that use of "Raffinate" at Champion International may be a source of copper. "Raffinate" is a black liquor high in sodium purchased by Champion International for use as salt cake make-up. The product contains 120 mg/kg copper (Fenske, F., personal communication).

The distribution of copper in surficial sediments is shown in Figure 7.4.9. The highest concentration (275 mg/kg dry weight) was found near the present location of the Champion International outfall. It is significant that the second highest concentration shown (180 mg/kg) was found off discharge PU-190, the site of the facility's previous outfall. Thus, high copper concentrations in sediment appear in both locations where plant effluent has been discharged. The PU-190 discharge was probably a significant source of copper prior to 1970, and only a periodic source during emergency plant bypasses since that time. The main plant outfall, SP-189, continues to be a major ongoing source of copper. Uniformly elevated copper concentrations throughout the SP-60 sediment core also support long-term input of copper.

Based on contaminant gradients, the known or potential presence of all contaminants of concern in the Champion International effluent, and a preliminary assessment of mass fluxes of some contaminants, the firm's main outfall appears to be the source of the contamination observed in samples from Stations SP-13 through SP-16. Given the proximity of the Puyallup River to the area of concern at the mouth of St. Paul Waterway, deposition of contaminated, river-borne particulates may contribute to the contamination. However, this contribution is not likely major because of the following reasons:

- The contaminants that have elevated concentrations in the area of concern have either been found in the Champion International effluent or can be associated with the pulp and paper industry in general. There are no substances showing elevated concentrations whose presence could be attributable only to an alternative source.

- Copper is introduced via the Champion International effluent. It has been found at 100 ug/L in the effluent and at elevated concentrations in sediments from the two areas where effluent has been discharged. The similarity of the copper distribution in the surficial sediments with the distributions of the other compounds suggests that the effluent is a source for all of the contaminants of concern.

- 2-Methoxyphenol (guaiacol) is a degradation product of lignin and thus is a good indicator of pulp and paper mill effluent. It has been tentatively identified in the effluent of the Tacoma Central sewage treatment plant at a concentration of 5 ug/L (Yake 1982c). Given the dilution of the treatment plant effluent by the Puyallup River (approximately 100:1) and the further dilution of the Puyallup River upon reaching Commencement Bay, it is unlikely that the Puyallup River is a significant source of this compound to this waterway.

- Coprostanol is an indicator of contamination by mammalian fecal material. Coprostanol concentrations in the sediments of St. Paul Waterway are the highest reported in the nearshore/tideflats area (up to 2,800 ug/kg at Station SP-11 near the head of the waterway), potentially because of the influence of the Puyallup River. The St. Paul Waterway station with the highest concentrations of the contaminants of concern (SP-14) had undetected concentrations of coprostanol. Therefore, if the Puyallup River is a major source of the coprostanol, and no coprostanol was found at the site of greatest contamination, the Puyallup River is unlikely to be the major source of that contamination (i.e., at Station SP-14).

- The Puyallup River plume can be expected to affect sediment quality to the north of the river mouth (Sitcum and Milwaukee Waterways) at least as much as areas to the south (St. Paul Waterway). Therefore, if the Puyallup River were the major source of the contaminants of concern, their concentrations in Sitcum and Milwaukee Waterways should be at least as great as those in St. Paul Waterway. Because this is not the case (with the exception of copper in Sitcum Waterway likely derived from local sources), the Puyallup River does not appear to be the major source of the contamination observed in St. Paul Waterway.

7.4.5 Summary and Recommendations

Champion International is implicated as the major source of all preliminary contaminants of concern in St. Paul Waterway. The proximity of the most contaminated sediments to the firm's main outfall indicates that this discharge is the route of contaminant input. The BOD/COD discharge is ongoing, and chemical analyses of the effluent (1981 Class II survey) indicated that discharge of at least naphthalene, chloroform, and copper was ongoing at that time. There is no reason to believe that the presence of any of the contaminants of concern is strictly a result of historical discharge.

Efforts should be directed toward reducing or eliminating discharge of the contaminants of concern via the Champion International main outfall. Because this is an NPDES-permitted discharge, the NPDES program should provide the mechanism to accomplish this goal. Further impetus for regulation is provided by the fact that U.S. EPA water quality criteria for copper are violated in the vicinity of the outfall, and that significant bioaccumulation of copper was found in English sole from St. Paul Waterway. Without source control, removal of contaminated sediments presently in the bay or St. Paul Waterway cannot be justified for other contaminants. Source control alone would probably be adequate to reduce dramatically sediment contamination by naphthalene and 4-methylphenol. Given the solubility of these compounds, they would not be expected to persist in the sediments if the effluent source were eliminated. On the other hand, if alkylated phenols are produced by in situ degradation of pulping waste products or wood chip debris buried in the sediments, there may be continued high levels for a considerable period of time. Copper would also be expected to persist in the sediments for many years even if source control were initiated. This is demonstrated by the elevated copper concentrations that have persisted at the pre-1970 Puyallup River outfall site.

7.5 MIDDLE WATERWAY

7.5.1 Introduction

Middle Waterway was created prior to 1923 (Hart-Crowser and Associates undated). With minor exceptions, the waterway remains unchanged from its original configuration. Unlike the other waterways in the tideflats, much of Middle Waterway (approximately the upper half) remains intertidal.

Several industries are located along the waterfront, as shown in Figure 7.51. On the east side, Paxport Mills operates a sawmill that produces cedar fencing and alder paneling. The remainder of the waterfront on the east peninsula south of Paxport Mills is occupied by Champion International, formerly St. Regis Paper Company. It was originally the location of the St. Paul and Tacoma Lumber Company, which opened a mill in the area in 1889 (Morgan and Morgan 1984).

Other industries that used to be located on or around Middle Waterway include several foundries and metalworking companies, three oil companies, three lumber companies, two maritime industries, and a coal products manufacturer. There are also references to a facility using creosote for timber treatment in the 1910s. No further information is available on any of these historical industries.

Middle Waterway is bordered on the south by 11th Street and two businesses: Washington Belt and Drive, and Western Machine. Pacific Yacht Basin, a fire station, and a utility substation occupy the southwest corner of the waterway. Coast Craft, a custom woodworking firm, occupies the southern shoreline near the head of the waterway. The remainder of the western shoreline is occupied by maritime industries including Foss Launch and Tug (a Dillingham Maritime Company), Marine Industries Northwest, and Cook's Marine Specialties.

There has been only one dredge and fill project within the waterway since 1970. In 1982 Paxport Mills reset a seawall and filled an area on the east side of the waterway to provide additional storage area for hog fuel. Approval of this project by the Corps of Engineers and WDOE was contingent upon the development of a salmon enhancement area near the mouth of Middle Waterway along the northwest shore. This enhancement area would replace the intertidal area that was destroyed when Paxport constructed their hog fuel storage area. Under the terms of the permit (071-OYB-2-006450-R), this area was to receive clean fill and clean dredge spoils. Instead, Paxport used wood wastes mixed with ASARCO slag as the fill material. The U.S. EPA and the Corps of Engineers plan to take enforcement action against Paxport, and WDOE has withdrawn their approval of the project (Ruckelshaus, M., 2 August 1985, personal communication). Other dredging projects include Puget Sound Plywood located at the end of the peninsula separating Middle and City Waterways in 1972 and 1978 to deepen the channel near their mill.

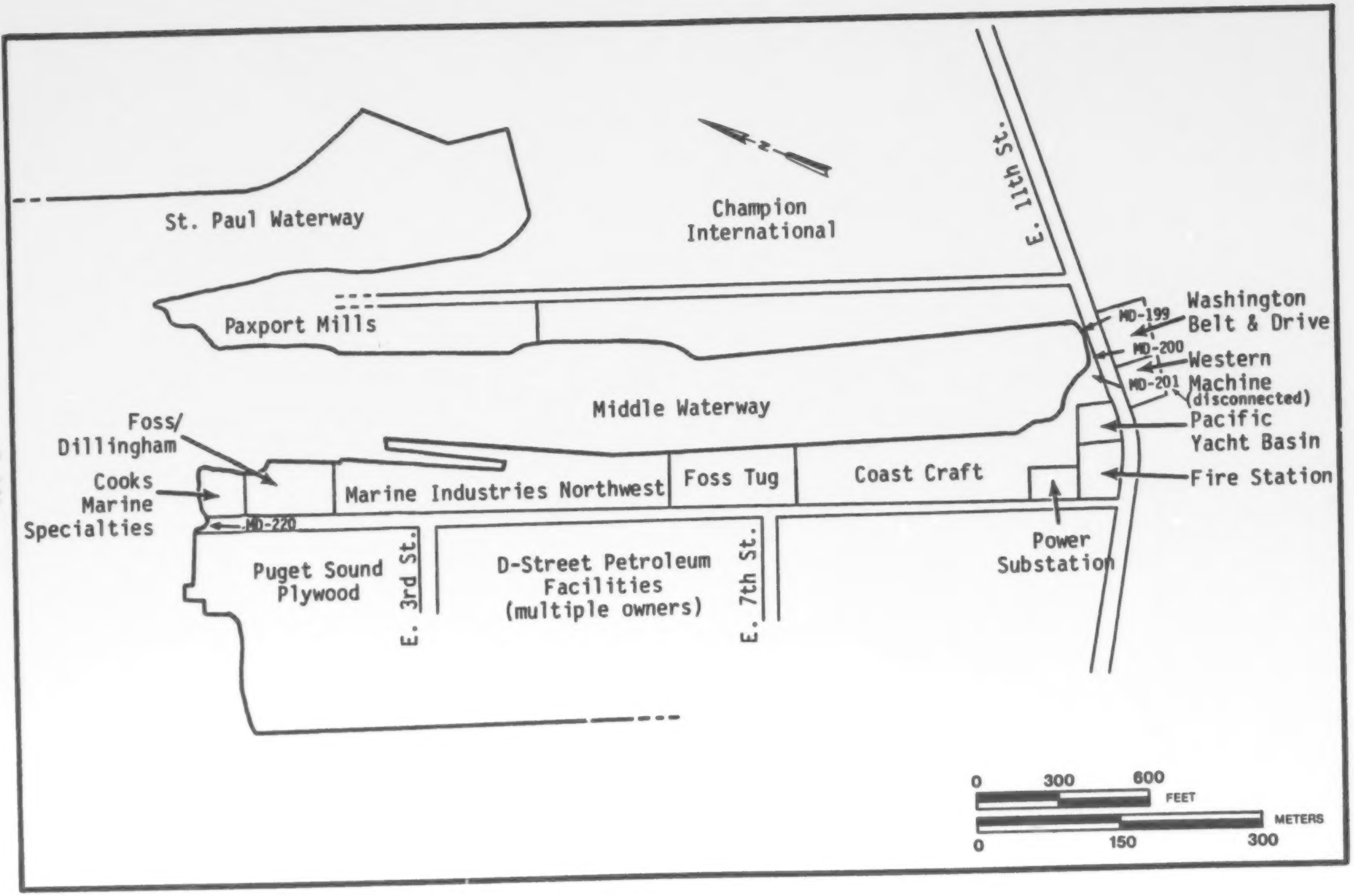


Figure 7.5.1

MAJOR INDUSTRIES AND DISCHARGES TO THE MIDDLE WATERWAY
INDUSTRY BOUNDARIES APPROXIMATE, BASED ON DRIVE-BY INSPECTION

There are no NPDES-permitted discharges to Middle Waterway. The largest outfall is a 27-in storm drain (MD-200) that discharges at the head of the waterway.

Locations of sediment chemistry stations in Middle Waterway are shown in Figure 7.5.2, including those sampled as part of the Superfund investigation and all historical sampling sites. Preliminary contaminants or contaminant groups of concern in Middle Waterway include

Organic Compounds	Inorganic Substances
Pentachlorophenol	Copper
Dichlorobenzenes	Mercury
Aromatic hydrocarbons	
Dibenzofuran	

The spatial distributions, known loadings, and potential sources of these compounds are discussed below. Concentrations of these preliminary contaminants of concern were later determined to exceed toxicity or benthic AET in sediments from at least one station in Middle Waterway. Other substances that were present above AET at a single station only (Priority 3 chemicals; see Table 6.14 in Section 6) but for which sources have not yet been evaluated include

Substance	Station Where AET Exceeded
Phenol	MD-11
4-Methylphenol	MD-13
Arsenic	MD-13
Zinc	MD-01

Except phenol, concentrations of these substances exceeded AET only when normalized to percent fine-grained material. Additional tentatively identified substances include dibenzothiophene (Station MD-11), methylpyrenes (Station MD-01), and two diterpenoid hydrocarbons (Station MD-01). Except dibenzothiophene, these compounds exceeded AET only when normalized to percent fine-grained material. These lower priority substances are not discussed further.

Average mass flux estimates were calculated only for copper and mercury in Middle Waterway. Source data for other contaminants were insufficient for analysis. Mass flux estimates for copper and mercury were evaluated using average concentrations of these contaminants in sediments from all present and historical stations according to the procedures and criteria outlined in Section 2.12.3.2. The source-derived mass flux for both metals was less than 1 percent of the sediment concentration-derived mass flux. According to the uncertainty criteria for this analysis, a data gap in the identification of copper and mercury sources is indicated. This conclusion is reasonable given that the highest sediment concentrations were observed at the opposite end of Middle Waterway from the MD-200 outfall, the only established source of copper and mercury.

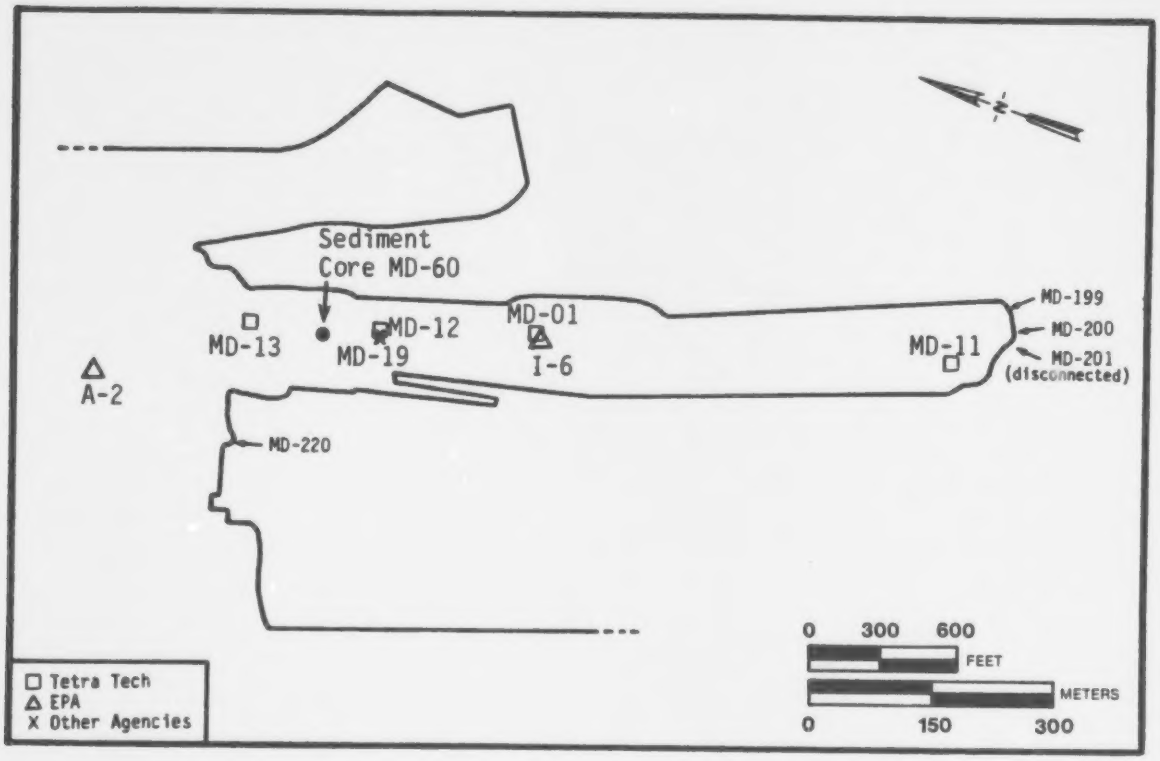


Figure 7.5.2

SURFICIAL SEDIMENT STATIONS AND SEDIMENT CORE LOCATIONS
FROM ALL STUDIES IN MIDDLE WATERWAY

7.5.2 Pentachlorophenol and Dichlorobenzenes

7.5.2.1 Spatial Distribution--

Concentrations of several organic compounds decreased along the length of Middle Waterway, with sediment concentrations at the head of the waterway several times greater than those at the mouth. These compounds included 1,2-dichlorobenzene, 1,4-dichlorobenzene, 1,2,4-trichlorobenzene, phenol, alkylated phenols, and pentachlorophenol. Of these, pentachlorophenol and the dichlorobenzenes are of concern. Concentrations of pentachlorophenol and 1,4-dichlorobenzene in the surficial sediments of Middle Waterway are shown in Figures 7.5.3 and 7.5.4.

Sediment contaminant data were collected at only a few stations in Middle Waterway. Therefore, evaluation of spatial gradients is limited. For both pentachlorophenol and 1,4-dichlorobenzene, the highest dry-weight concentrations were measured in the intertidal area near the head of the waterway. Upper Middle Waterway is an intertidal depositional environment and organic carbon levels are higher in surficial sediments than in deeper sediments. The available data are not sufficient to determine whether the observed levels of pentachlorophenol and 1,4-dichlorobenzene result from sources near the waterway head, or from transport and deposition of contaminated sediments originating elsewhere in the waterway.

A single sediment core sample was taken near the mouth of Middle Waterway (Station MD-60). Pentachlorophenol and dichlorobenzene concentrations (ug/kg dry weight) within this core were

	Pentachlorophenol	1,2-Dichlorobenzene	1,4-Dichlorobenzene
Horizon 1 (0-0.13 m)	undetected at 25	10.8	29.7
Horizon 2 (0.13-0.32 m)	undetected at 50	undetected at 5	undetected at 5

These data indicate that dichlorobenzene input is either recent or ongoing. The pentachlorophenol detection limits were too high to draw any conclusions regarding contaminant input over time for this compound. None of these concentrations exceed AET.

7.5.2.2 Loading Estimates--

There are three discharges at the head of Middle Waterway: a seep (MD-199), a 27-in storm drain (MD-200), and a 4-in PVC pipe (MD-201). Only MD-200 effluent has been analyzed for pentachlorophenol or dichlorobenzene. This discharge was analyzed on three occasions between April, 1982 and May, 1984 and in all cases was found to contain undetectable concentrations of both pentachlorophenol and the dichlorobenzenes (WDOE unpublished). Detection limits ranged from 1 to 10 ug/L.

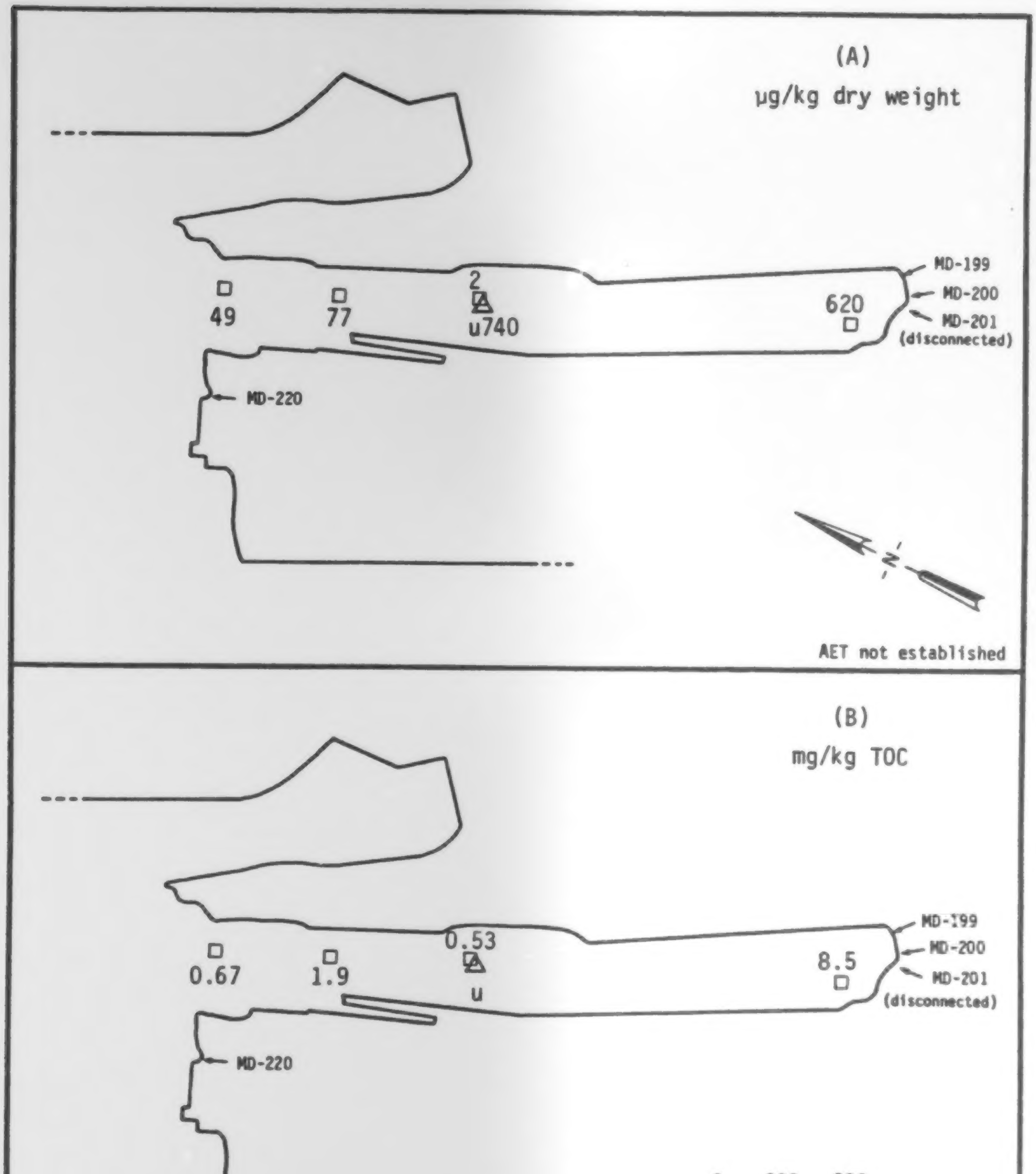


Figure 7.5.3

CONCENTRATIONS OF PENTACHLOROPHENOL IN THE SURFICIAL SEDIMENTS OF MIDDLE WATERWAY

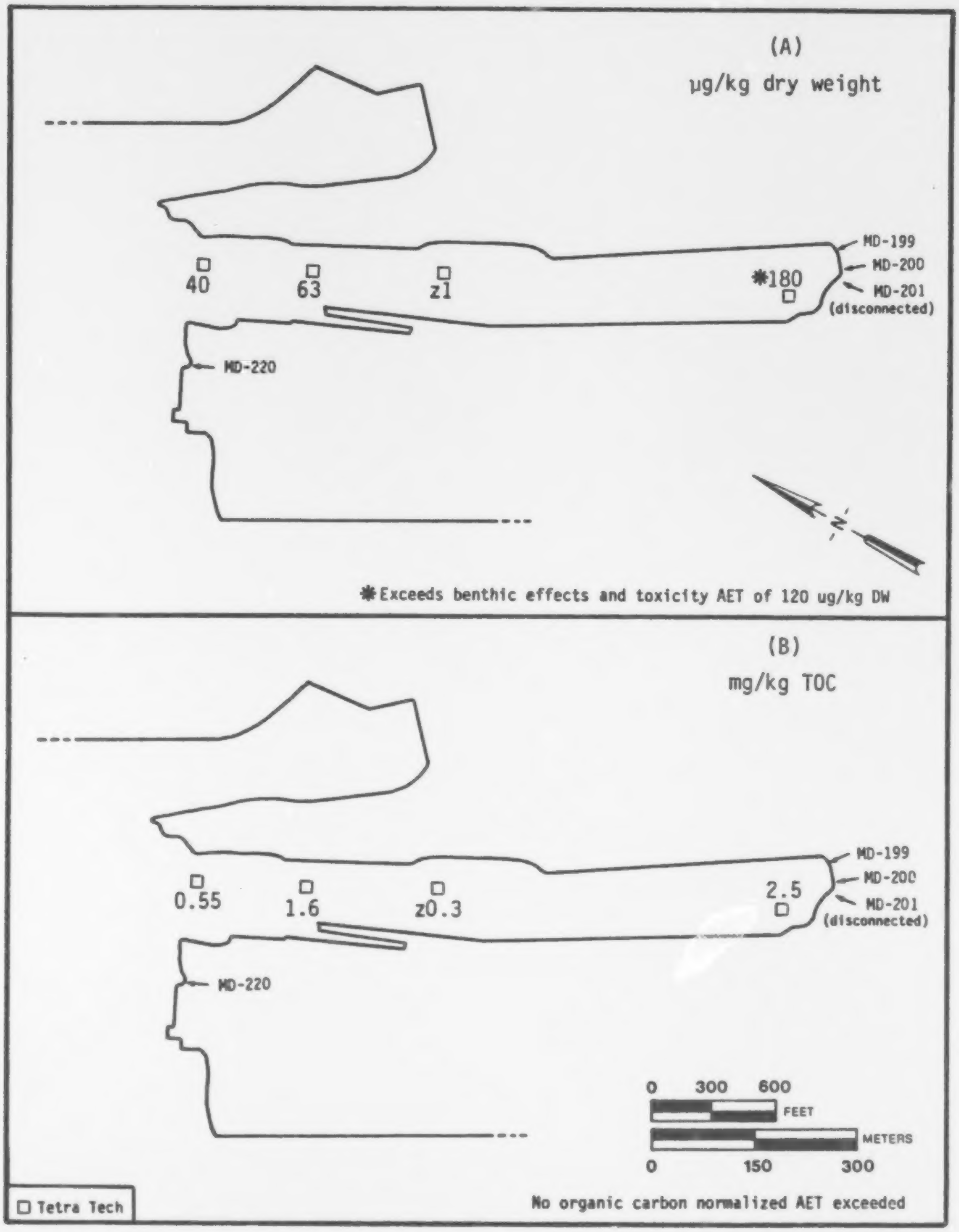


Figure 7.5.4

CONCENTRATIONS OF 1,4-DICHLOROBENZENE IN THE SURFICIAL SEDIMENTS OF MIDDLE WATERWAY

7.5.2.3 Source Identification--

The spatial distributions of pentachlorophenol and dichlorobenzenes in the surficial sediments of Middle Waterway suggest at least one source at the head of the waterway. No known discharge to Middle Waterway contains either pentachlorophenol or dichlorobenzenes, but potential sources can be identified in order to aid further investigative activity.

Pentachlorophenol is a bactericide, fungicide, and slimicide used primarily for wood preservation (U.S. EPA 1980b). There are two wood products industries in the tideflats area from which a discharge would reach the head of Middle Waterway: Champion International and Coast Craft. Champion International is located along the eastern shore of Middle Waterway. Runoff from the Champion International log storage, debarking, and sawing areas could reach the head of Middle Waterway via the MD-200 storm drain. Dames and Moore (1982) noted that prior to 1975-76, a "Permatox" dip tank was maintained on site. "Permatox" is a fungicide and anti-stain agent containing mercury and tetra- and/or pentachlorophenate salts. The pentachlorophenate salt would not be expected to be transformed to pentachlorophenol at pH conditions typical of the marine environment (Schellenberg et al. 1984). Therefore, "Permatox" is not considered to be the source of the pentachlorophenol observed in Middle Waterway. However, the types and volumes of preservatives used by Champion International since 1976, if any, have not been established. The WDOE is unaware whether wood preservatives are currently in use on-site (Fenske, F., personal communication).

Coast Craft is located at 1002 East F Street at the head of Middle Waterway along the western shore. The firm performs custom woodworking and treats lumber with wood preservatives. In the Tacoma Tideflats Industrial Survey conducted by the Pierce County Health Department, it was reported that Coast Craft had a pentachlorophenol dip tank (Pierce, R., 15 July 1985, personal communication).

There is no documented source of dichlorinated benzenes to Middle Waterway. Therefore, source identification efforts must focus on uses of the compounds. The uses of 1,2-dichlorobenzene include (Hawley 1981)

- Solvent for a wide range of organic materials
- Solvent for nonferrous metals
- Degreasing of hides and wool
- Metal polishing
- Industrial odor control
- Dye manufacturing

- Production of 3,4-dichloroaniline and toluene diisocyanate
- Heat transfer.

1,4-Dichlorobenzene is used as an air deodorant and an insecticide, which account for 90 percent of its total production (U.S. EPA 1980c).

No single major source of these contaminants to Middle Waterway can be identified based on these uses. The shoreline surrounding the head of the waterway is occupied by Coast Craft (custom woodworking) to the west, piles of sawdust from Champion International to the east, and Pacific Yacht Basin, a marine supply store, at the southern end. None of these sites appears to be a likely source of the chlorinated benzenes. The drains and seeps at the head of the waterway are possible sources. The MD-200 storm drain has the largest flow volume of these discharges. Based on a review of drainage maps provided by Tacoma-Pierce County Health Department and the Tacoma Department of Public Works, this drain serves East 11th Street (from East F Street to Portland Avenue) and Portland Avenue (from East 11th Street to 0.7 km east of the 11th/Portland intersection). Most of this area is occupied by Champion International. Discharge MD-201, a 4-in pipe from Pacific Yacht, has been abandoned, and the origin of the MD-100 seep is unknown.

7.5.2.4 Summary and Recommendations--

Highest sediment concentrations of both pentachlorophenol and the dichlorinated benzenes were measured near the head of Middle Waterway, indicating the possible presence of a source in this area. Although there has been no documented discharge of pentachlorophenol or dichlorinated benzenes to the waterway, Champion International (formerly St. Regis) and Coast Craft are potential sources of pentachlorophenol, based on the use of the compound in the wood products industry and the fact that discharge from the facilities can reach the head of Middle Waterway either directly or via the storm sewer network. The presence of pentachlorophenol in surface sediments indicates that contamination is either recent or ongoing. Input of dichlorinated benzenes appears to be either recent or ongoing. The ultimate source of the compounds could not be identified.

The following recommendations can be made based on source identification efforts:

- The use of wood preservatives at Coast Craft and Champion International should be investigated. In particular, it should be established whether pentachlorophenol-based preservatives have been used, whether this use is continuing, and, if it is, whether the compound may be entering the waterway.
- Sediment samples at the discharge points of MD-199 and 200 should be taken and analyzed for chlorinated benzenes. Once the source discharge is identified, the drainage area should be delineated and appropriate industries investigated

for the potential use and discharge of products containing dichlorinated benzenes.

- More surface sediment sampling should be conducted to allow better spatial resolution of distributions of pentachlorophenol and dichlorinated benzenes.

- A subsurface core should be taken at the head of the waterway.

7.5.3 Aromatic Hydrocarbons and Dibenzofuran

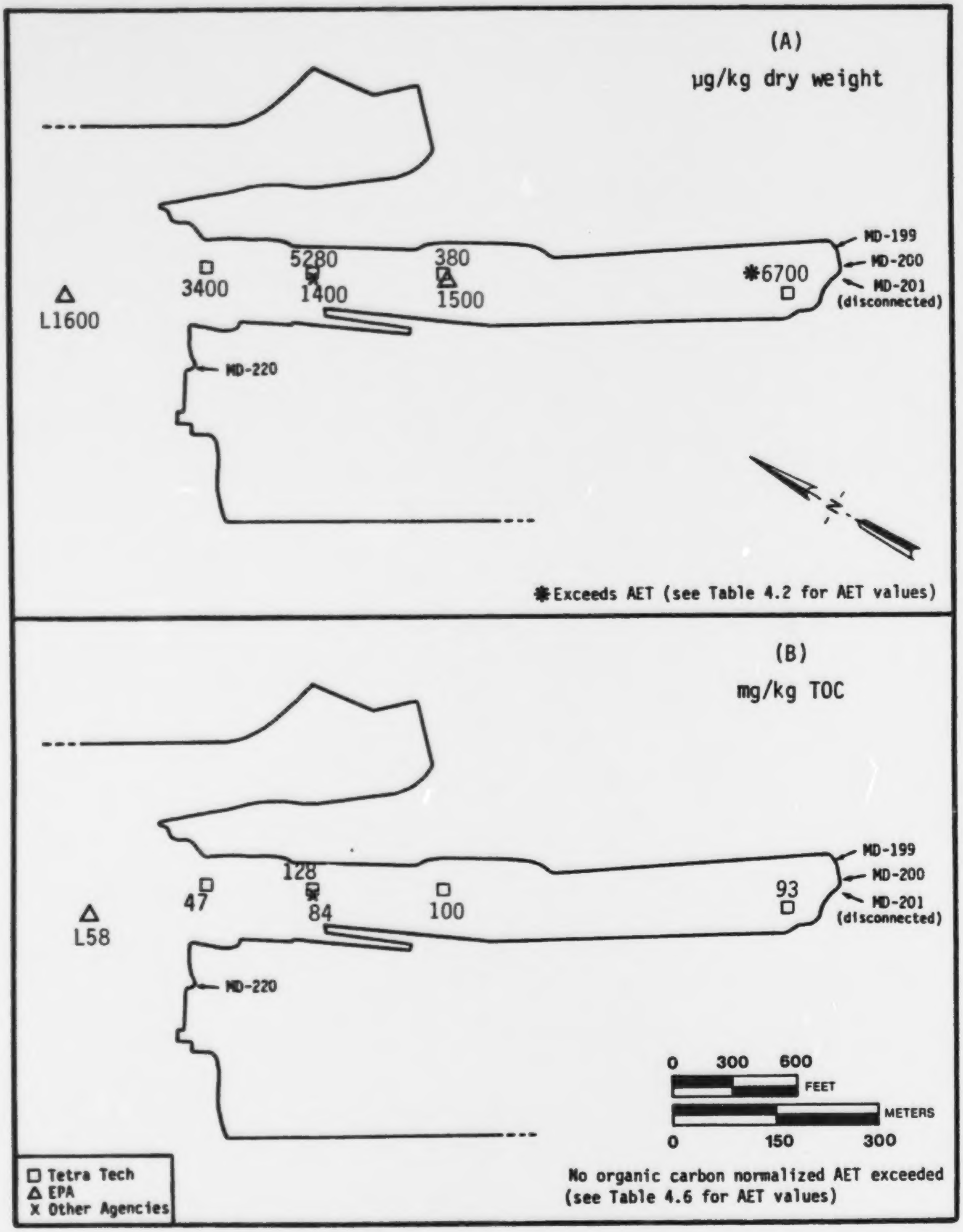
7.5.3.1 Spatial Distribution--

Distributions of polycyclic aromatic hydrocarbons (PAH) and dibenzofuran in surficial sediments of Middle Waterway are shown in Figures 7.5.5-7.5.7. LPAH, HPAH, and dibenzofuran all displayed similar distributions. Samples from Station MD-01, located approximately midway along the length of the waterway, had the lowest concentrations on a dry-weight basis. These low concentrations were probably a consequence of the coarse sediments and low organic content of these sediments, since when normalized to organic carbon, concentrations at this station were comparable to others in the vicinity. Dry-weight concentrations of LPAH, HPAH, and dibenzofuran were somewhat lower at the mouth of the waterway (MD-13) than at the head of the waterway. However, after normalization to organic carbon, the concentrations were highest near the mouth (e.g., Station MD-12). Lower concentrations at stations outside Middle Waterway and directly at the waterway mouth (i.e., Station MD-13) suggested that contaminants were not advected from the bay into the waterway. Beyond this, there was no clear gradient of contamination with which to establish the location of potential sources.

As shown below, PAH concentrations in the sediment core sample taken near the mouth of the waterway station (MD-60) were slightly higher in the lower horizon than in the upper horizon, suggesting a slight decrease in the rate of contaminant input in recent years. Dibenzofuran concentrations were approximately equal in the two horizons sampled. These values are comparable to the concentration of LPAH and dibenzofuran in surface sediments from Middle Waterway. HPAH concentrations were twice as high in the sediment core samples than in the surface sediments.

	LPAH (ug/kg DW)	HPAH (ug/kg DW)	Dibenzofuran (ug/kg DW)
Horizon 1 (0-0.13 m)	5,300	15,300	480
Horizon 2 (0.13-0.32 m)	7,300	16,700	470

LPAH and HPAH concentrations in the core exceeded AET. The dibenzofuran concentrations did not exceed AET.


(A)

µg/kg dry weight

*Exceeds AET (see Table 4.2 for AET values)

(B)

mg/kg TOC

No organic carbon normalized AET exceeded (see Table 4.6 for AET values)

Figure 7.5.5

CONCENTRATIONS OF LOW MOLECULAR WEIGHT PAH IN THE SURFICIAL SEDIMENTS OF MIDDLE WATERWAY

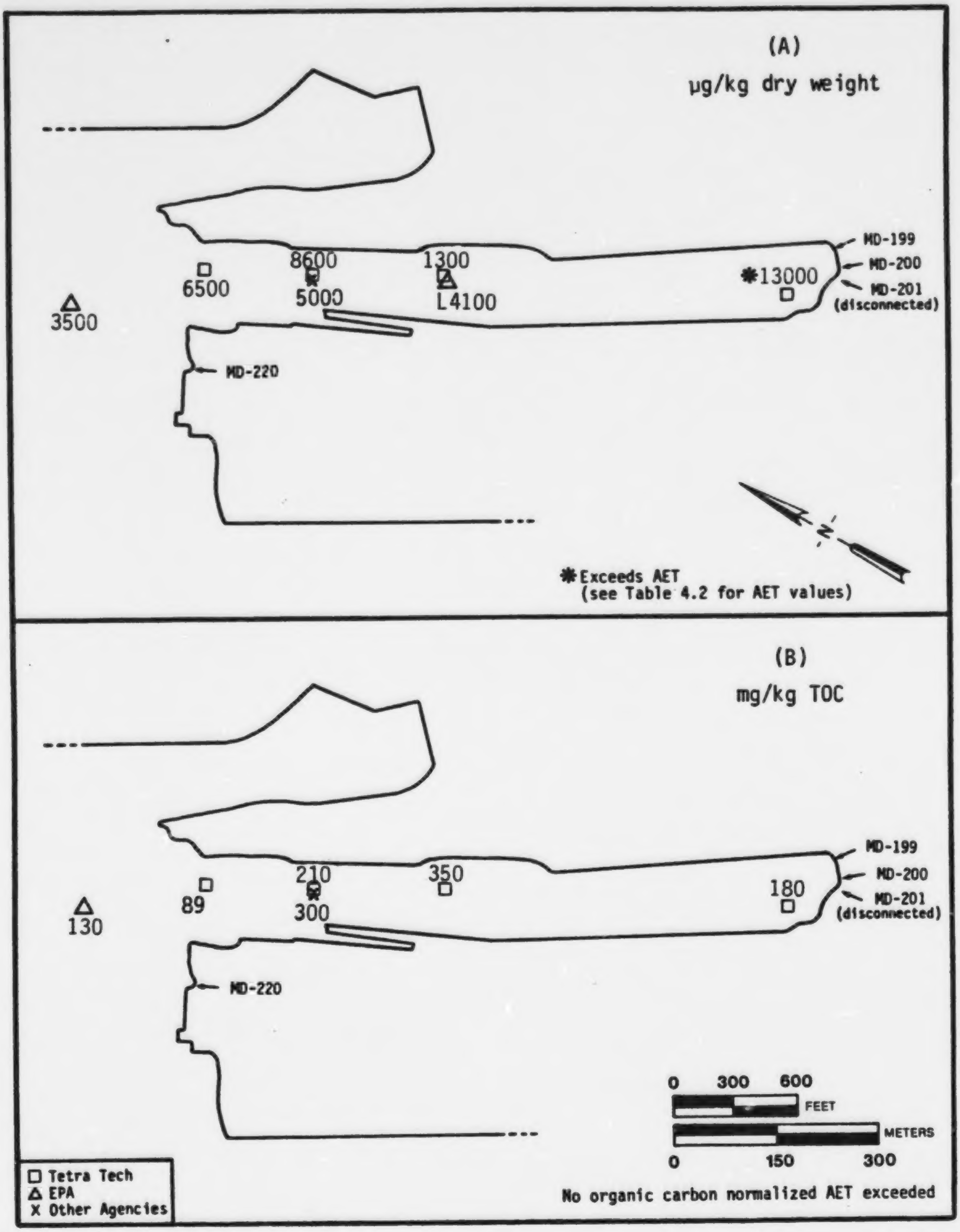


Figure 7.5.6

CONCENTRATIONS OF HIGH MOLECULAR WEIGHT PAH IN THE SURFICIAL SEDIMENTS OF MIDDLE WATERWAY

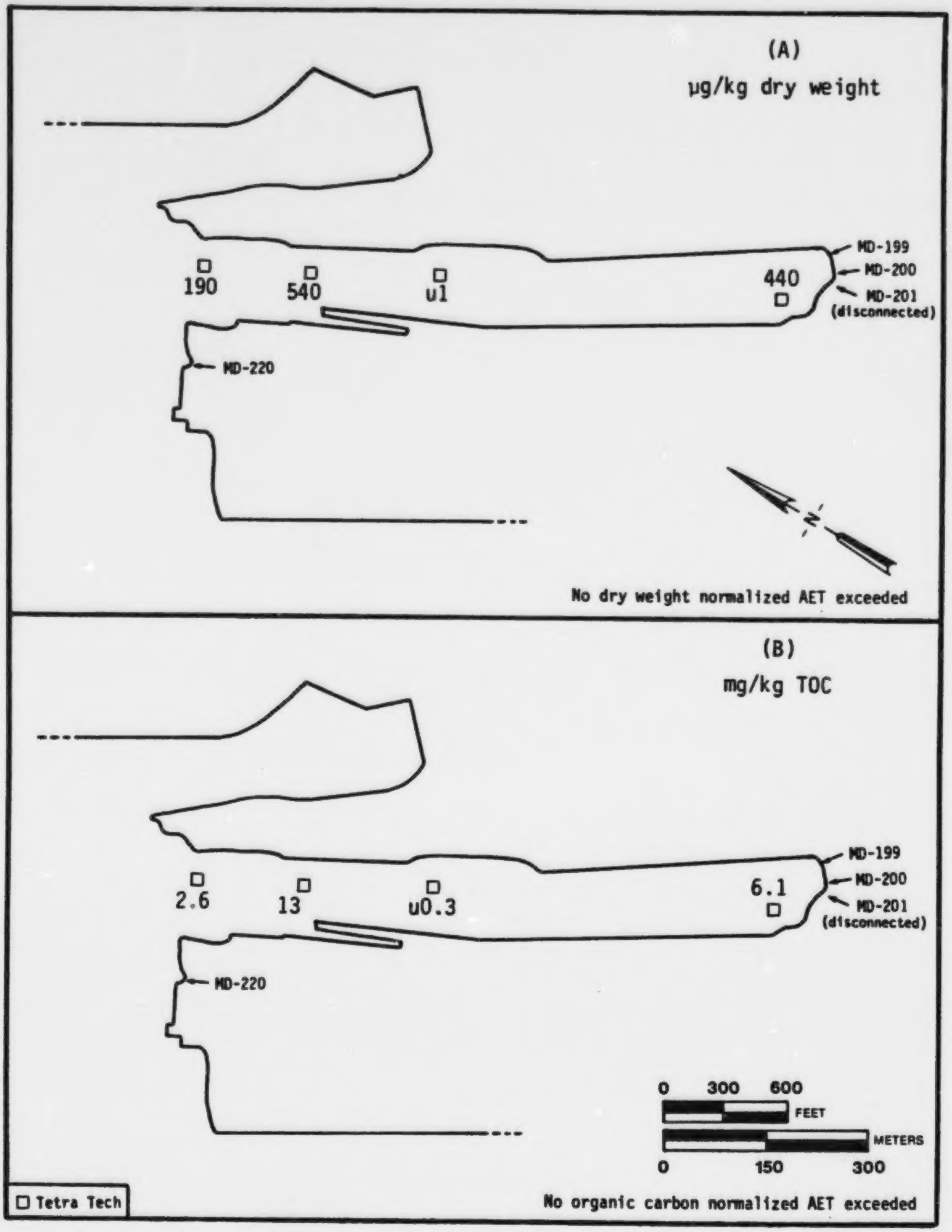


Figure 7.5.7

CONCENTRATIONS OF DIBENZOFURAN IN THE SURFICIAL SEDIMENTS OF MIDDLE WATERWAY

7.5.3.2 Loading Estimates--

The only discharge to Middle Waterway that has been analyzed for PAH is MD-200. The effluent from this drain was analyzed three times between April, 1982 and May, 1984. No PAH were found at detection limits ranging from 0.1 to 10 ug/L (WDOE unpublished). Dibenzofuran analyses were performed twice in the spring of 1984. On both occasions, the compound was undetected at 0.1 ug/L.

7.5.3.3 Source Identification--

Source identification efforts were complicated by the absence of clear gradients of PAH and dibenzofuran contamination along the length of the waterway. If, as suggested by the highest concentrations of PAH at the head of the waterway, the storm sewer represents the greatest contributor (dry-weight basis), then efforts to locate the ultimate source should focus on the drainage area served (see Section 7.5.2.3). The high contaminant concentrations observed on a normalized basis within the central portion of the waterway could have originated from the ship repair facilities along the western shore. There is no known documented release from these facilities based on a review of WDOE Environmental Complaint files, 1978-1985. However, a long-term, chronic discharge of PAH may be expected from runoff and activities such as bilge pumping.

7.5.3.4 Summary and Recommendations--

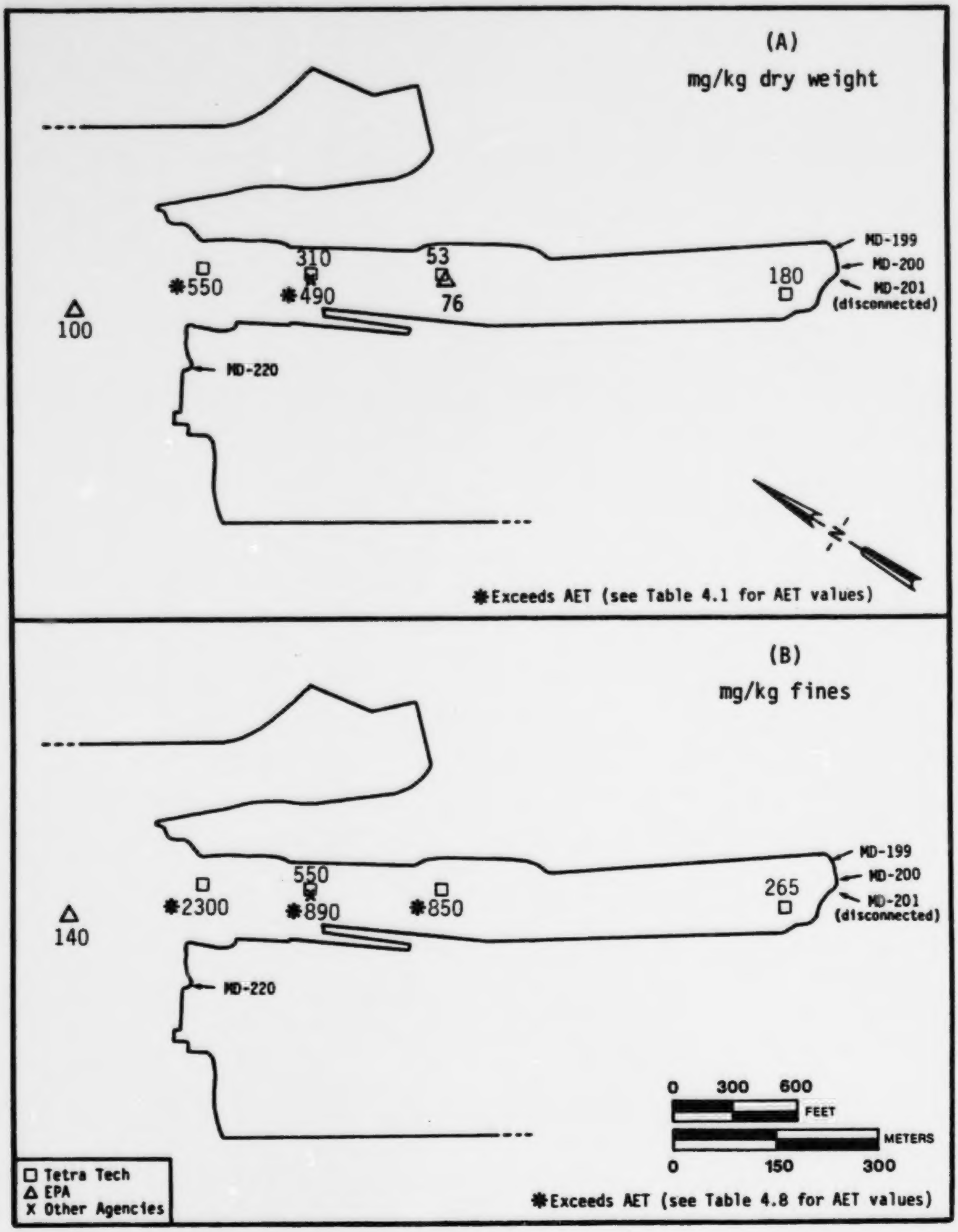
A major source for PAH could not be clearly established. These compounds are ubiquitous in highly industrialized areas such as Commencement Bay, and sources such as spills and bilge pumpage are not possible to quantify. Further source identification efforts will require more intensive sediment sampling to better define gradients of contamination suggested by the limited data available. Additional sampling of discharges to Middle Waterway is recommended.

7.5.4 Mercury and Copper

7.5.4.1 Spatial Distribution--

Concentrations of copper and mercury in the surficial sediments of Middle Waterway are shown in Figures 7.5.8 and 7.5.9, using data from the Tetra Tech 1984 survey and all available historical data. The highest concentrations normalized to both dry-weight and to percent fine-grained material were found at the mouth of the waterway (Station MD-13). The decrease in metal concentrations with distance up the waterway, particularly apparent for mercury, suggests that a source is located near the waterway mouth.

A single sediment core sample was taken near the mouth of the waterway within 100 m of the area of greatest surficial sediment contamination. Copper and mercury concentrations (mg/kg) were as follows:



✱Exceeds AET (see Table 4.1 for AET values)

✱Exceeds AET (see Table 4.8 for AET values)

Figure 7.5.8

CONCENTRATIONS OF COPPER IN THE
SURFICIAL SEDIMENTS OF MIDDLE WATERWAY

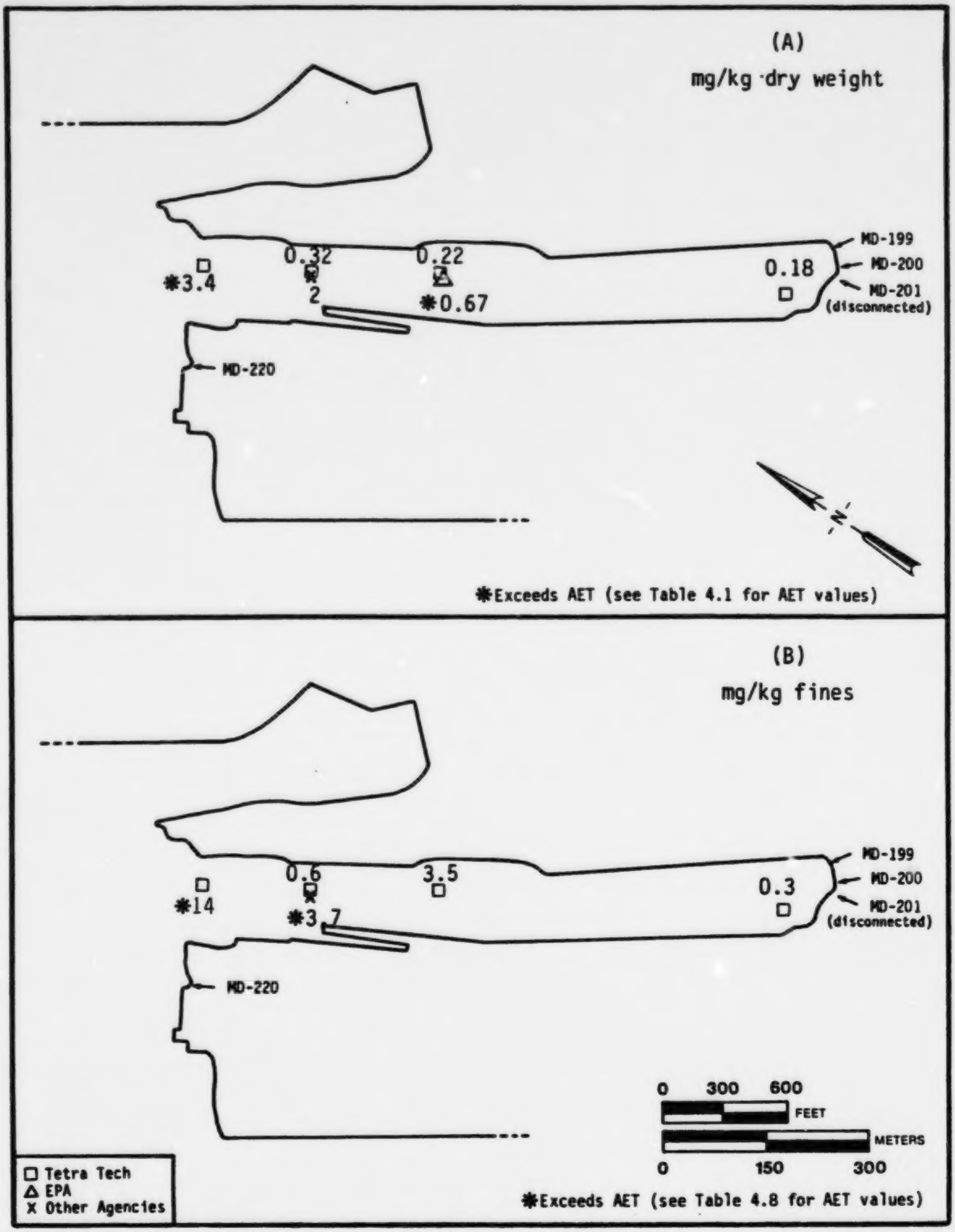


Figure 7.5.9

CONCENTRATIONS OF MERCURY IN THE SURFICIAL SEDIMENTS OF MIDDLE WATERWAY

	Copper	Mercury
Horizon 1 (0-0.13 m)	435	4.2
Horizon 2 (0.13-0.32 m)	126	0.8

These data indicate that recent metal input, represented by Horizon 1, is 3.5 to 5 times greater than historical input, represented by Horizon 2. Concentrations of copper exceeded AET only in Horizon 1. Mercury concentrations exceeded AET in both horizons.

7.5.4.2 Loading Estimates--

MD-200 is the only discharge to Middle Waterway for which the effluent has been analyzed for copper or mercury. Based on a flow of 0.3 MGD and a copper concentration of 30 ug/L measured in the effluent in April, 1982 (WDOE unpublished), a copper loading of 0.0075 lb/day can be estimated. The estimated mercury loading from the drain was 0.000053 lb/day, based on detection of 0.21 ug/L in April, 1984 (WDOE unpublished).

7.5.4.3 Source Identification--

The spatial gradient of metals contamination in the surficial sediments of Middle Waterway suggests that the source of the metals is located near the mouth of the waterway. A gradient of decreasing concentrations with distance from the mouth could be the result of contaminant input from Commencement Bay. However, this does not appear to be the case since similar upwaterway gradients should be apparent in other waterways but are not. Decreasing metals concentrations with distance from the mouth were apparent only for Middle Waterway. Therefore the source is apparently unique to the waterway.

Champion International, known to be a source of copper to St. Paul Waterway, may also be the major source of copper to Middle Waterway. However, this hypothesis does not appear reasonable for three reasons. First, copper concentrations were higher in Middle waterway by a factor of two than observed in any St. Paul Waterway sediment. Second, there was no consistent gradient of copper concentrations between the two waterways (compare Figure 7.5.8 with Figure 7.4.9 in Section 7.4). Third, mercury, as well as copper, showed increased concentrations at the mouth of Middle Waterway, yet Champion International is not known to be a significant source of mercury, and elevated mercury concentrations occurred only in Middle Waterway sediments.

The most probable explanation for the observed pattern of contamination is the presence of a source near the mouth of Middle Waterway. Paxport Mills is located on the east shore of the waterway near the mouth. Release of metals would not be expected since the firm is a sawmill and would not typically handle metal-contaminated products. Paxport recently used a mixture of wood wastes and ASARCO slag to fill a salmon enhancement area adjacent to their property near the mouth of the waterway. This project was completed in 1982. Sediment samples were not collected from this area. As discussed below, the relative concentrations of arsenic and copper in sediments near the mouth of Middle Waterway were not consistent with those found in ASARCO slag.

The western shoreline of the lower waterway is occupied by three maritime industries (Cook's Marine Specialties, Foss Tug, and Marine Industries Northwest), each of which is involved in ship repair. A shipbuilding firm has been implicated as a source of metals to City Waterway because of the use and disposal of sandblasting grit in the waterway. Ship repair facilities in southern California are major sources of copper and other metals because of their use of metal-based antifouling paints (Young et al. 1979). Therefore, ship repair facilities along the western shore of Middle Waterway may be the source of the metals observed in Middle Waterway sediments. There are too few sampling sites in the waterway to conclusively determine whether this is the case. However, this determination could probably be made with additional sampling data.

Sandblasting grit is one potential source of metals from ship repair facilities. Up through the 1970s, ship repair firms in the tideflats area typically used ASARCO slag for sandblasting. Its use has been documented at Peterson Boat Building (Dames and Moore 1982), which occupied (until 1981) the property now owned by Cook's Marine Specialties. Ship repair firms have since switched to commercially available sandblasting preparations, such as "Tuf-Kut". In order to determine if sandblasting grit is responsible for the metals contamination observed in Middle Waterway, the relative proportion of metals in Middle Waterway sediments was compared to that in (1) ASARCO slag, (2) a Pt. Defiance Shoreline station that showed visual evidence of a high ASARCO slag content, (3) "Tuf-Kut" sandblasting material, and (4) City Waterway sediments known to have a high content of sandblasting grit (ASARCO slag and/or "Tuf-Kut"). Arsenic- to-heavy metals ratios in each of these materials are shown in Table 7.5.1. The Middle Waterway sediments had proportionately more copper and proportionately less arsenic and zinc than either ASARCO slag or the Ruston-Pt. Defiance sediments contaminated with ASARCO slag. In comparison to "Tuf-Kut," the Middle Waterway sediments had proportionately much less copper. From these data, it appears that either the ship repair firms along Middle Waterway are using sandblasting products other than ASARCO slag or "Tuf-Kut," or some material other than sandblasting grit is the major source of the metals contamination observed.

Antifouling paints may be a potential source for these metals. A wide variety of metals are used as toxicants in antifouling paints, including copper, mercury, and tin. These and other metals have been found at elevated concentrations in marine sediments adjacent to ship repair facilities (Young et al. 1979). Although the data are inadequate to draw definitive conclusions, antifouling paints removed by sandblasting may be contributing to the metal contamination observed in Middle Waterway sediments.

Table 7.5.1

COMPARISON OF ARSENIC AND METAL RATIOS IN MIDDLE WATERWAY SEDIMENTS

	Contaminant Concentration (mg/kg) and Ratio			
	As	Zn	Cu	Hg
Mouth of Middle Waterway (MD-13)	67 (1)	158 (2.4)	554 (8.3)	3.4 (0.051)
ASARCO slag[a]	9,000 (1)	18,000 (2)	5,000 (0.55)	no data
Pt. Defiance shoreline (RS-24)	700 (1)	1,620 (2.3)	385 (0.55)	0.41 (0.00059)
"Tuf-Kut" blasting sand[b]	<0.8[c] (1)	75 (93.8)	1,300-5,000 (1,600-6,250)	0.06 (0.75)
City Waterway off Martinac Shipbuilding[b] (WDOE Station CS-5)	197 (1)	2,100 (10.7)	2,160 (11)	0.035 (0.00018)

---

[a] Source: State of Washington Discharge Permit Application, 1971, ASARCO

[b] Source: Norton and Johnson 1984.

[c] The arsenic concentration of <0.8 mg/kg was supplied by the manufacturer of "Tuf-Kut." In May 1980, the Washington Department of Industry, Division of Industrial Safety and Health, analyzed the "Tuf-Kut" blasting sand at Peterson Boats for arsenic and reported 20 mg/kg (J. Burt, Division of Industrial Safety and Health pers. comm.).

7.5.4.4 Summary and Recommendations--

The gradient of metals contamination along the length of Middle Waterway suggests that the source of copper and mercury is located near the waterway mouth. The sediment core data indicate that this source is recent and possibly ongoing. The only known discharge to Middle Waterway containing heavy metals is at the head of the waterway (the MD-200 storm sewer outfall). The ship repair facilities along the western shore of Middle Waterway (i.e., Cook's Marine Specialties, Foss Tugs, and Marine Industries Northwest) appear to be the most probable source of the copper and mercury in the waterway sediments. The use and/or removal of antifouling paints containing copper and mercury may generate metals. Release of sandblasting grit, while not the sole source of the metals, may also be a contributing factor.

A WDOE inspection of the ship repair facilities near the mouth of Middle Waterway is recommended. This inspection should emphasize sandblasting practices and the extent to which blasting grit and bottom paints may be reaching the waterway. Further sampling of waterway sediments is recommended to better define spatial gradients of contamination and to determine whether one of the several ship repair firms is the major source of metals.

7.5.5 Middle Waterway: Summary and Recommendations

Of the six preliminary contaminants or contaminant groups designated to be of concern in Middle Waterway, possible sources for three (pentachlorophenol, copper, mercury) have been identified. It is possible that dichlorobenzenes and PAH are entering the waterway via the storm sewer system or possibly via one of the other discharges at the head of the waterway. Ultimate sources within the drainage area could not be identified.

Five industries have been identified as possible sources based on their potential use of products containing the contaminants of concern and their potential discharge to areas of the waterway showing the highest sediment contaminant concentrations. These industries include:

- Champion International (or its predecessor, St. Regis Paper Company) - potential source of pentachlorophenol via the storm sewer system (may account for high sediment concentrations near the drain at the head of the waterway)
- Coast Craft - potential unconfirmed source of pentachlorophenol (used as a wood preservative) by spillage or other unauthorized discharge
- Cook's Marine Specialties, Foss Tug, and Marine Industries Northwest - potential sources of copper and mercury by release of antifouling paints, sandblasting material, or other products used in ship repair

- Paxport Mills - potential source of metals and organic compounds from a wood waste and ASARCO slag mixture used as fill in a salmon enhancement area near the mouth of the waterway.

There has been no documented discharge of these preliminary contaminants of concern from any named facility to Middle Waterway. However, inspection of all these facilities is recommended. Until this inspection is completed and sources of these contaminants can be better identified, no further recommendations regarding source control can be made, nor can the effectiveness of source control be evaluated. Specific recommendations for each preliminary contaminant and contaminant group were discussed elsewhere in Section 7.5.

7.6 CITY WATERWAY

7.6.1 Introduction

The body of water that is now City Waterway was originally bounded by the bluffs of Old Tacoma and the western side of the Puyallup River delta. The 1886 nautical charts of the area (Hart-Crowser and Associates undated) show shallows and mudflats across much of this area. Settlement of Tacoma began along the western bluffs overlooking the tideflats, and as early as the 1860s, wharves were built along the bluffs to accommodate ship traffic (Morgan and Morgan 1984). The wharves were used to store coal, grain, and wood for shipment to other ports. The lumber milling industry began to expand as port facilities increased. By 1873, the Northern Pacific Railroad had reached Tacoma. The terminus of the railroad, complete with dock facilities, was built on the west side of the waterway near what is now Stadium Way. The railroad provided the impetus for industrial development near the city and across the tideflats. Old photographs show the western shore of the waterway bulwarked against erosion by 1890. The first known dredging occurred in 1890 when the Tacoma Land Company deepened the channel for vessel entry. By 1894, the City Waterway had reached its present length and width. Wheeler-Osgood Waterway was formed prior to 1894 from the old western channel of the Puyallup River.

Industries along the waterfront in the 1890s and early 1900s included 10 - 15 warehouses and dock storage facilities, at least seven lumber mills, two foundries, several food processing and storage companies, and two electric companies. Industries presently surrounding City Waterway are shown in Figure 7.6.1. Harmon Furniture, Fick Foundry, Northern Fish Products (now Ocean Fish), and Union Oil of California were present prior to 1920 (Ruckelshaus 1985). Much of the western shore of the waterway is occupied by marinas and storage facilities. North Pacific Plywood, located on the western shore since at least 1960, recently moved to Graham, Washington. Harmon Furniture, George Scofield Company, two seafood processors, and a wholesale produce distributor remain on the west side. Major reconstruction on the west side of the waterway is occurring with the building of a new 15th Street bridge across the waterway.

American Plating is located near the head of the waterway along its eastern shore. The firm has been present at this location (with other names and owners) since about 1955. Marinas front the eastern shoreline of the waterway as far north as 15th Street. Burlington Northern and Union Pacific Railroad Yards and several large grocery warehousing facilities are on the east side of D Street near the head of the waterway. Martinac Shipbuilding, north of 15th Street, has been at this location since 1925. Wheeler-Osgood Waterway is ringed by abandoned buildings, warehouses, and several small industries with unknown operations. Hygrade Foods, Carsten's Meat Packers prior to 1960, is situated east of Wheeler-Osgood Waterway.

Woodworth and Company, a construction firm present since the 1930s; Fick Foundry, present as early as 1920; Globe Machine; Olympic Chemical; and the D Street petroleum facilities with multiple owners (Mobil, Shell,

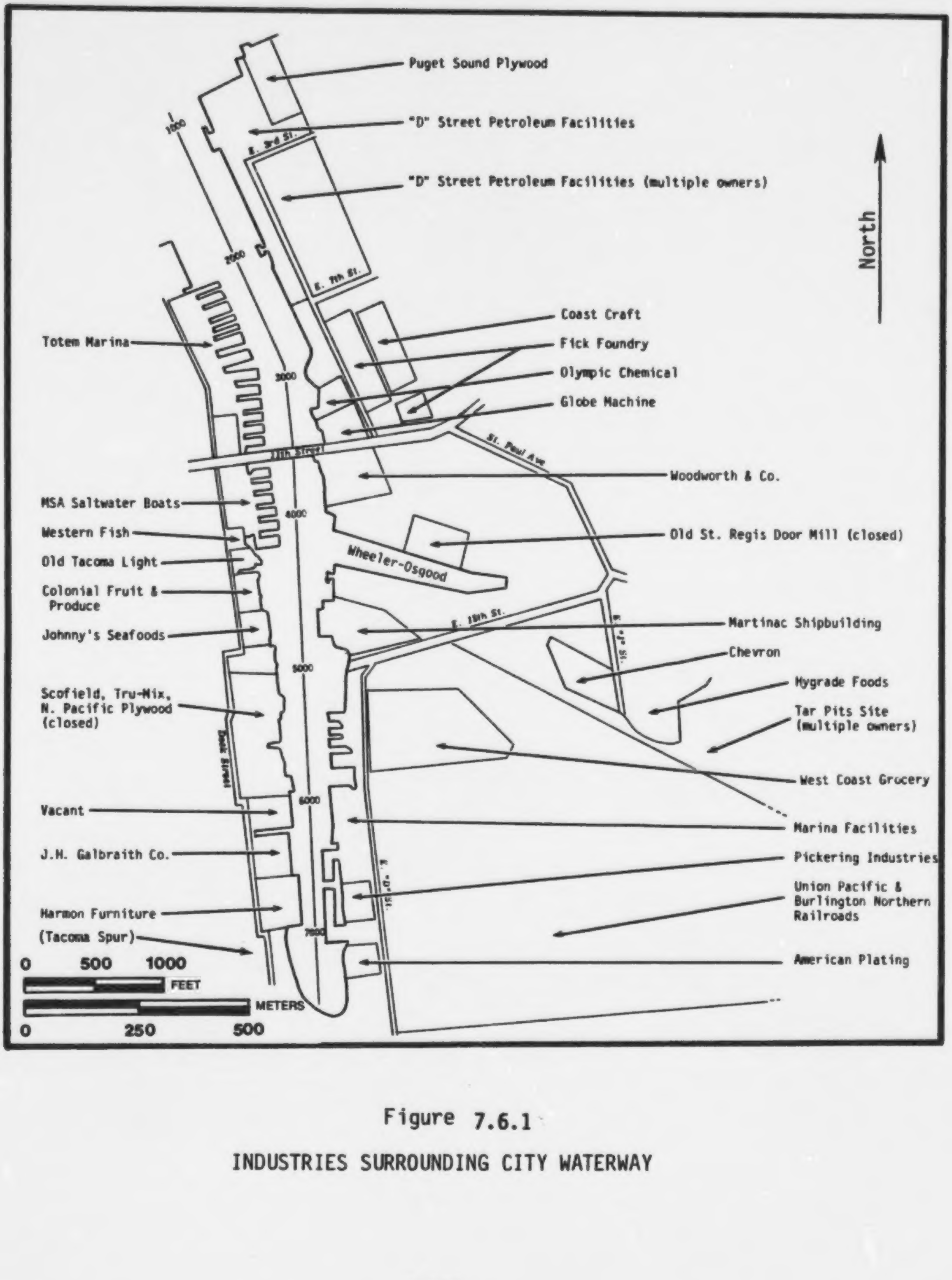


Figure 7.6.1

INDUSTRIES SURROUNDING CITY WATERWAY

Union and Superior oil companies) are located north of Wheeler-Osgood Waterway, along City Waterway. Portions of the D Street tank farms have been present since the 1920s.

Dredging in City Waterway by the U.S. Army Corps of Engineers has not occurred since 1948; however, there have been several dredging activities by private companies. A summary of recent dredging projects in City Waterway is presented in Table 7.6.1. The Corps dredged the waterway every 3 to 12 yr between 1905 and 1948 (Johnston 1981). Since that time, minor revisions in shore configuration have been conducted mainly to install docks and marina facilities. U.S. Army Corps of Engineers permit records indicate construction of bulkhead and docks for marina facilities for MSA Salt Water Boats on the west side of the waterway south of 15th Street, Pickering Industries, and the Picks Cove restaurant area next to Pickering Industries. None of these minor projects was in an area sampled by Tetra Tech or WDOE during these Superfund investigations.

Major discharges into City Waterway, shown in Figure 7.6.2, include the locations of major storm drains serving the waterway and the industrial discharges permitted under the NPDES permit program. All NPDES-permitted discharges to City Waterway are classed as minor industrial discharges. NPDES permits for these industries typically include permit limits for flow, pH, temperature, total oil and grease, and BOD. They do not include discharge limits or monitoring requirements for U.S. EPA priority pollutants.

Storm drains entering City Waterway have served the area since the turn of the century. Until 1979, six major combined drains serving 11,000 ac and a population of 60,000 or more discharged to City Waterway. These drains included the 11th, 15th, and 21st Street drains (CI-235, CI-230, CI-234, respectively); the Nalley Valley drain (CN-237); the south Tacoma drain (CS-237); and the drain at the head of Wheeler-Osgood Waterway (CW-254). Discharge of sanitary sewage through these drains was substantially decreased in 1969 by efforts to separate the storm and sanitary sewers in the city of Tacoma. Intermittent discharge of sewage through some of these drains continued until 1979. Presently, the discharge from these drains to the waterway consists of urban stormwater runoff. The Nalley Valley and south Tacoma drains, at the head of the waterway, have the largest flows and serve a major portion of the urban Tacoma area. Total suspended solids (TSS) in these two storm drains are as high as 320 mg/L during storm events (Johnson and Norton 1984c). Although it has a smaller discharge, the 15th Street drain may carry suspended solids concentrations of similar magnitude. The drain at the head of Wheeler-Osgood Waterway and the 11th and 21st Street drains serve much smaller areas than the other drains, have much smaller flows, and generally have lower TSS values.

7.6.2 Contaminants of Concern

Locations of sediment chemistry stations in City Waterway, including those sampled as part of the Superfund investigation and all historical sampling sites are shown in Figure 7.6.3. City Waterway has been divided into three segments: upper City Waterway to approximately 3,800 ft from

TABLE 7.6.1. SUMMARY OF DREDGING PROJECTS, CITY WATERWAY

Year	Permitee	Quantity (yd^3)	Comments/Status[a]
1975	City of Tacoma	4,750	Completed in 1977
1977	Johnny's Dock Restaurant	8,464	Completed
1977	Pickering Industries	2,100	Completed
1978	Morris and Sons	2,500	Completed (per file note)
1979	M. W. Perrow	4,820	Completed
1981	S. Jones	3,600	Status unkown
1982	J. E. Meaker	364	
1983	Superior Oil Company	5,000	

[a] Except where noted, all project status was verified by Duane Karna, U.S. EPA.

Reference: U.S. Army Corps of Engineers dredging permits, as compiled by M. Ruckelshaus, WDOE.

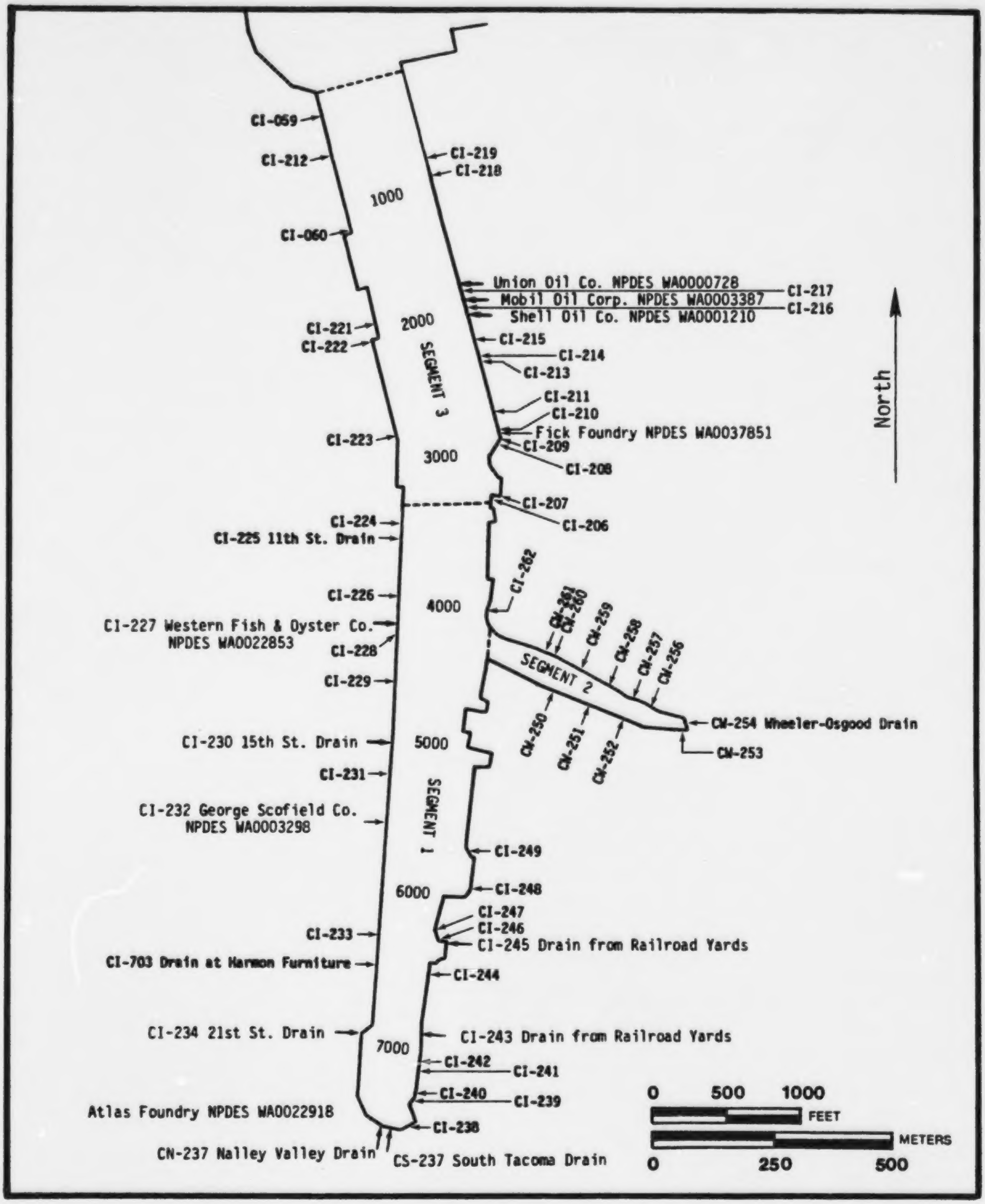


Figure 7.6.2

STORMDRAIN LOCATIONS AND NPDES PERMITTED DISCHARGE LOCATIONS IN CITY WATERWAY

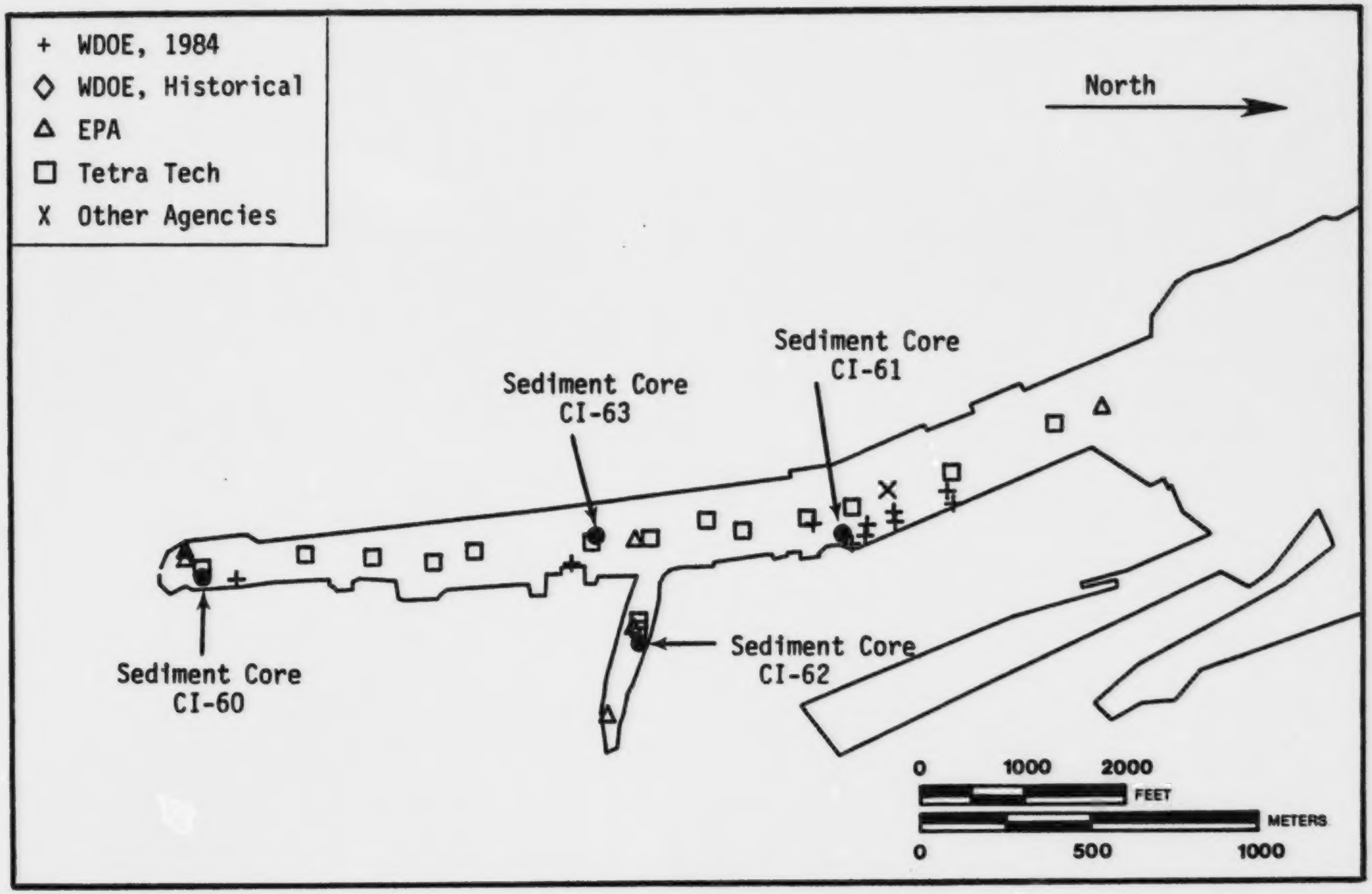


Figure 7.6.3

SURFICIAL SEDIMENT STATIONS AND SEDIMENT CORE LOCATIONS
FROM ALL STUDIES IN CITY WATERWAY

the mouth (Segment 1); Wheeler-Osgood Waterway (Segment 2); and lower City Waterway to the mouth (Segment 3). Eight chemicals or groups of chemicals plus organic enrichment have been named as contaminants of concern in one or more segments of City Waterway. These contaminants and their respective areas of concern include:

Organic Compounds	Metals
Organic enrichment (Segments 1, 2)	Copper (Segments 1 and 3)
Aromatic hydrocarbons (Segments 1, 2, and 3)	Lead (Segments 1 and 3)
Dibenzofuran (Segments 1 and 3)	Zinc (Segment 1)
Dichlorobenzenes (Segments 1, 2, and 3)	
4-Methylphenol (Segments 1, 2, and 3)	
PCBs (Segments 1 and 3)	

Dibenzofuran is listed as of preliminary concern in Segment 1 and 3 and source evaluations were conducted for this compound. It was later determined that concentrations of dibenzofuran did not exceed AET at any station in City Waterway. Concentrations of other chemicals listed above as of preliminary concern in Segments 1 and 2 did exceed AET for at least one station in those segments. Aromatic hydrocarbons, PCBs, and zinc concentrations exceeded AET in Segment 3, but concentrations of the other preliminary contaminants of concern in Segment 3 did not. PCBs were also of concern in this waterway because of significant bioaccumulation in English sole muscle tissue.

Other contaminants for which concentrations were ultimately determined to exceed AET (see Table 6.14 in Section 6) but were not subjected to source evaluations included:

Substance	Station Where AET (DW) Exceeded
2-Methylphenol	CI-12, CI-15
Phenol	CI-02, CI-11, CI-20
Benzyl alcohol	CI-11
N-nitrosodiphenylamine	CI-01, CI-02, CI-16, CI-18
Phthalate esters	CI-12, CI-13
Cadmium	CI-02, CI-12, CI-13, CI-14, CI-15, CI-18
Mercury	CI-01, CI-03, CI-11, CI-13, CI-18
Nickel	CI-11 and intertidal sediments

Aniline was detected at a single station (CI-01) at the head of City Waterway. AET could not be determined for this compound. Concentrations of two tentatively identified compounds were also determined to exceed AET in City Waterway [i.e., biphenyl in Segment 2 and 3, and dibenzothiophene in Segment 3). These latter substances likely share common sources with PAH.

Mercury was not of preliminary concern, but source evaluations are needed because it was later determined to be a Priority 1 chemical in City Waterway (i.e., mercury was present above AET and its concentration gradient covaried with changes in polychaete abundances; see Section 4.2.3.3). A brief summary of its distribution is presented here. Loading data are presented in the report on potential remedial technologies for the Commencement Bay nearshore/ tideflats remedial investigation (Tetra Tech 1985). Highest concentrations of mercury occurred at Stations CI-13 (1.1 ug/kg dry weight) and CI-18 (0.96 ug/kg dry weight). Even higher concentrations were found at depth in mid-channel cores from Stations CI-60, CI-61, and CI-63 (maximum 2.7, 1.6, and 2.5 ug/kg dry weight, respectively). The spatial pattern observed for mercury concentrations did not correlate well with that of other metals believed to derive primarily from drains at the head of City Waterway. Ninety-three percent of the known loading of mercury derives from the 15th Street drain (CI-230). The other substances for which source evaluations were not conducted are not discussed further.

The distribution of each preliminary contaminant of concern in the surficial sediments of City Waterway using data from Superfund studies and all historical information is presented in Figure 7.6.4. This figure is presented to show the areas of the waterway that are the most contaminated and to allow visual parallels to be drawn among the distributions of the contaminants. (Contaminants with similar distributions may have common sources.) The fine lines indicate areas where the concentrations of the contaminant exceeded the 80th percentile of that contaminant's concentrations in all stations sampled as part of this Superfund study. The heavy lines indicate areas that exceeded the 90th percentile of the concentrations in these stations. This figure illustrates areas of elevated concentrations for each contaminant. These areas may not coincide with those designated to be of concern for each contaminant, since the designation of an area of concern incorporates biological as well as chemical data.

Three trends are readily apparent from Figure 7.6.4:

1. A greater number of the contaminants of concern had elevated concentrations in sediments at the head of the waterway than near the mouth.

2. Copper, lead, zinc, and total organic carbon had similar concentration gradients, suggesting a common source for these four contaminants.

3. Several contaminants of concern showed elevated concentrations in Wheeler-Osgood Waterway, yet had much lower concentrations in nearby City Waterway sediments. This suggests the presence of sources in Wheeler-Osgood Waterway.

Average mass flux estimates were calculated for HPAH, LPAH, copper, lead, and zinc to enable a comparison of mass loadings of these contaminants relative to their sediment concentrations in City Waterway. Insufficient source data were available to calculate mass flux estimates for the other priority contaminants. The mass flux estimates were evaluated using average concentrations of the contaminants in sediments from all present and historical stations according to the procedures and criteria outlined in Section 2.12.3.2.

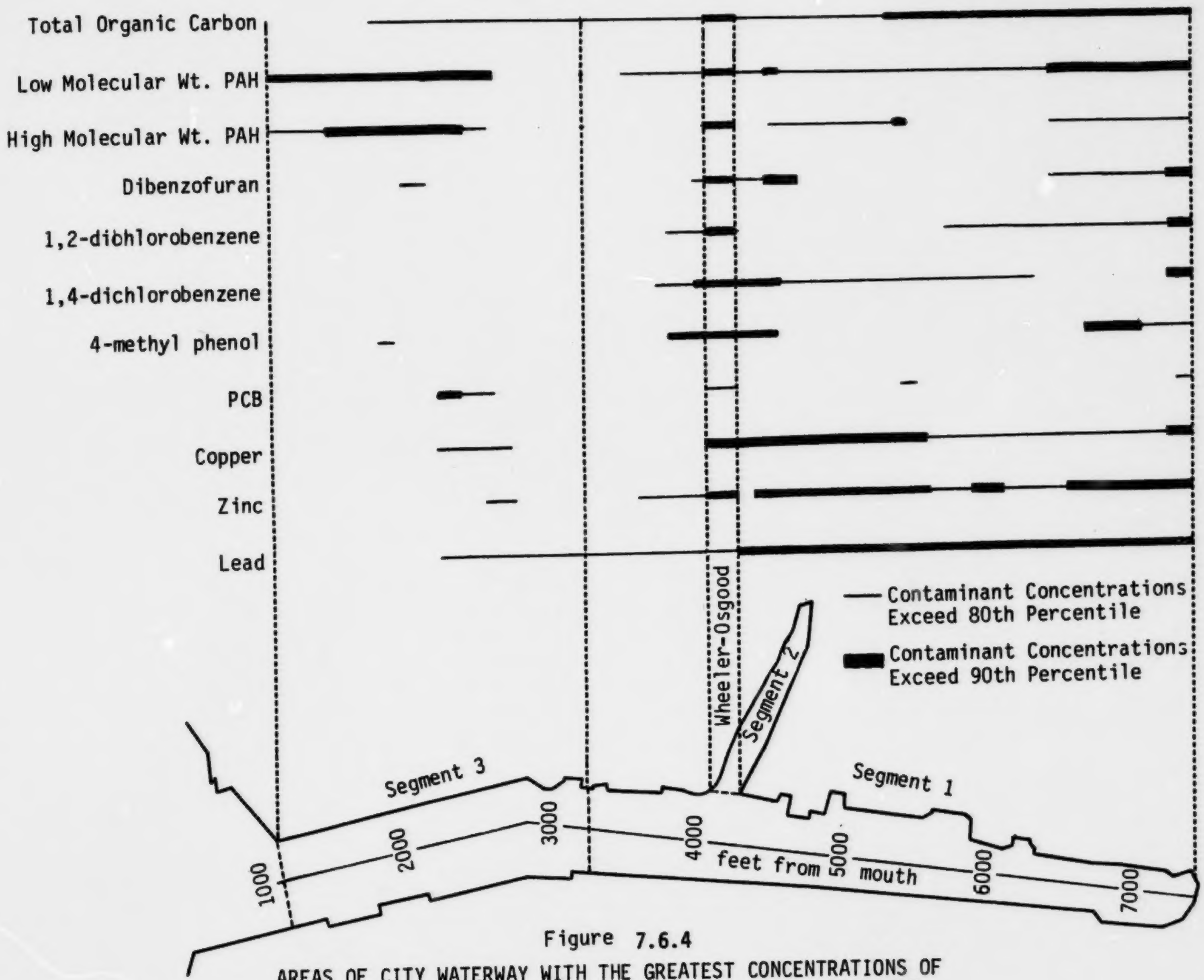


Figure 7.6.4

AREAS OF CITY WATERWAY WITH THE GREATEST CONCENTRATIONS OF EACH CONTAMINANT OF CONCERN IN THE SURFICIAL SEDIMENTS

All of the source-derived mass fluxes were within an order of magnitude of the concentration-derived mass fluxes with the exception of HPAH. Therefore, according to the uncertainty criteria for this analysis, no data gaps were indicated in accounting for major sources of LPAH, copper, lead, or zinc. The source-derived mass flux for HPAH was less than 1 percent of the concentration-derived mass flux. A data gap in the identification of HPAH sources was indicated.

In the following sections, each contaminant of concern is individually addressed. Its spatial distribution within the waterway sediments is discussed, contaminant loadings from known sources are presented, and all known or potential sources are evaluated. Two dimensional plots of contaminant concentrations, which have been used for other waterways to display spatial distributions, are not presented for City Waterway. Instead, all concentration plots are presented as changes in concentration with distance from the mouth of the waterway because of the linear arrangement of almost all stations. The location of critical stations is described in text when the spatial pattern was unclear from these plots.

7.6.3 Organic Enrichment

Sediment organic enrichment, measured as total organic carbon (TOC), represents a measurement of total organic content regardless of compound or oxidation state (American Public Health Association et al. 1981). It includes the organic carbon from detritus carried in stormwater runoff (e.g., leaves and bark), domestic and industrial wastewater organic chemicals, oils and grease, and all other organic contaminants entering the waterway.

7.6.3.1 Spatial Distribution--

Organic enrichment and anoxic sediments are of concern in Segments 1 and 2 of City Waterway. Waterway sediments (especially in Wheeler-Osgood Waterway) contained some of the highest levels of organic carbon seen anywhere in the tideflats area. In surficial sediments, concentrations of organic carbon decreased from the head of the waterway to the mouth (Figure 7.6.5). In Segment 2 (Wheeler-Osgood Waterway), organic carbon was measured at 10.9 - 18.0 percent. This pattern of organic enrichment indicates at least one source of organic carbon at the head of the waterway and another in the Wheeler-Osgood Waterway.

Organic carbon concentrations in sediment cores collected in City Waterway are shown in Figure 7.6.6. At the head of the waterway (Station CI-60, G05), organic carbon concentrations decreased only slightly with depth down to 4.3 ft (1.3 m) in the sediment column, indicating a relatively constant rate of accumulation of organic carbon over time. Core samples from Wheeler-Osgood Waterway (CI-62, G01, B02) and from City Waterway near the mouth of Wheeler-Osgood Waterway (CI-63, B01) did not penetrate as deeply as other City Waterway cores. However, there was little evidence of change in the rate of organic input to the depth sampled (1.3 ft; 0.4 m). Core CI-61, G01, collected in the lower third of the waterway (about 3,000 ft from the mouth) showed a fivefold increase in organic carbon beneath

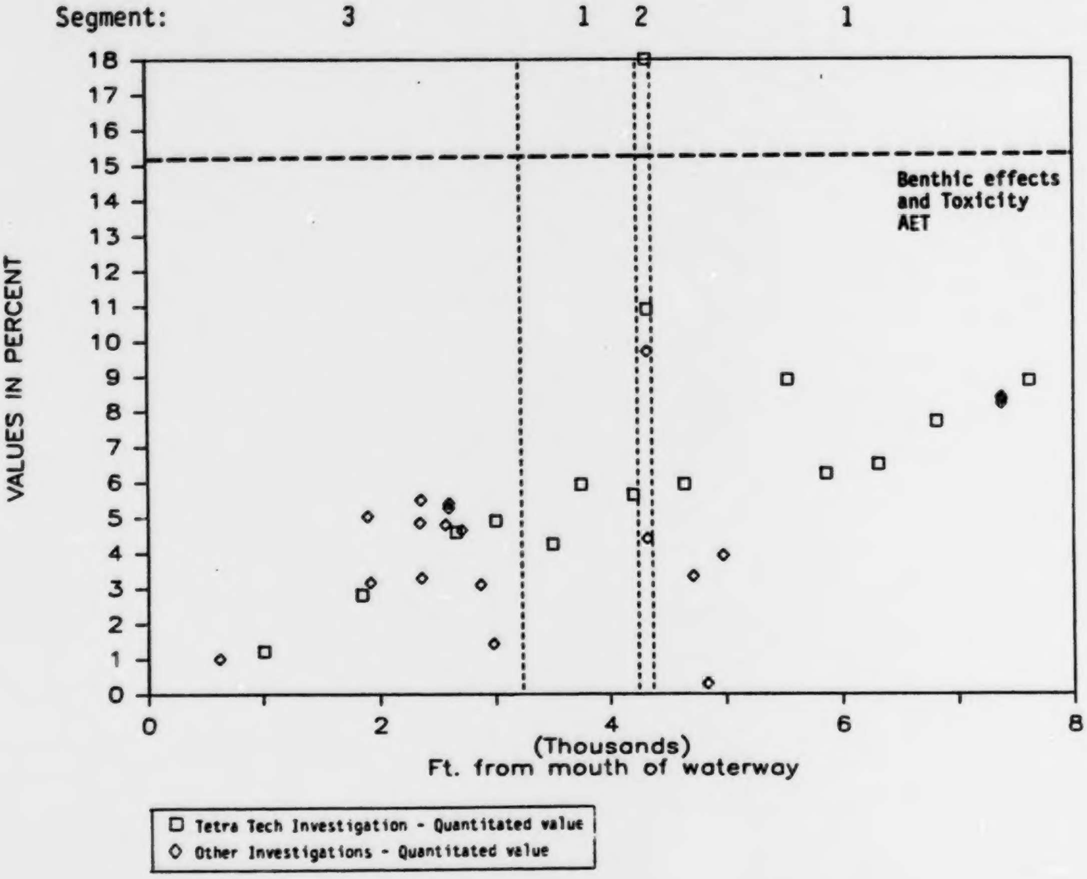


Figure 7.6.5

SURFICIAL SEDIMENT CONCENTRATIONS OF
TOTAL ORGANIC CARBON IN CITY WATERWAY

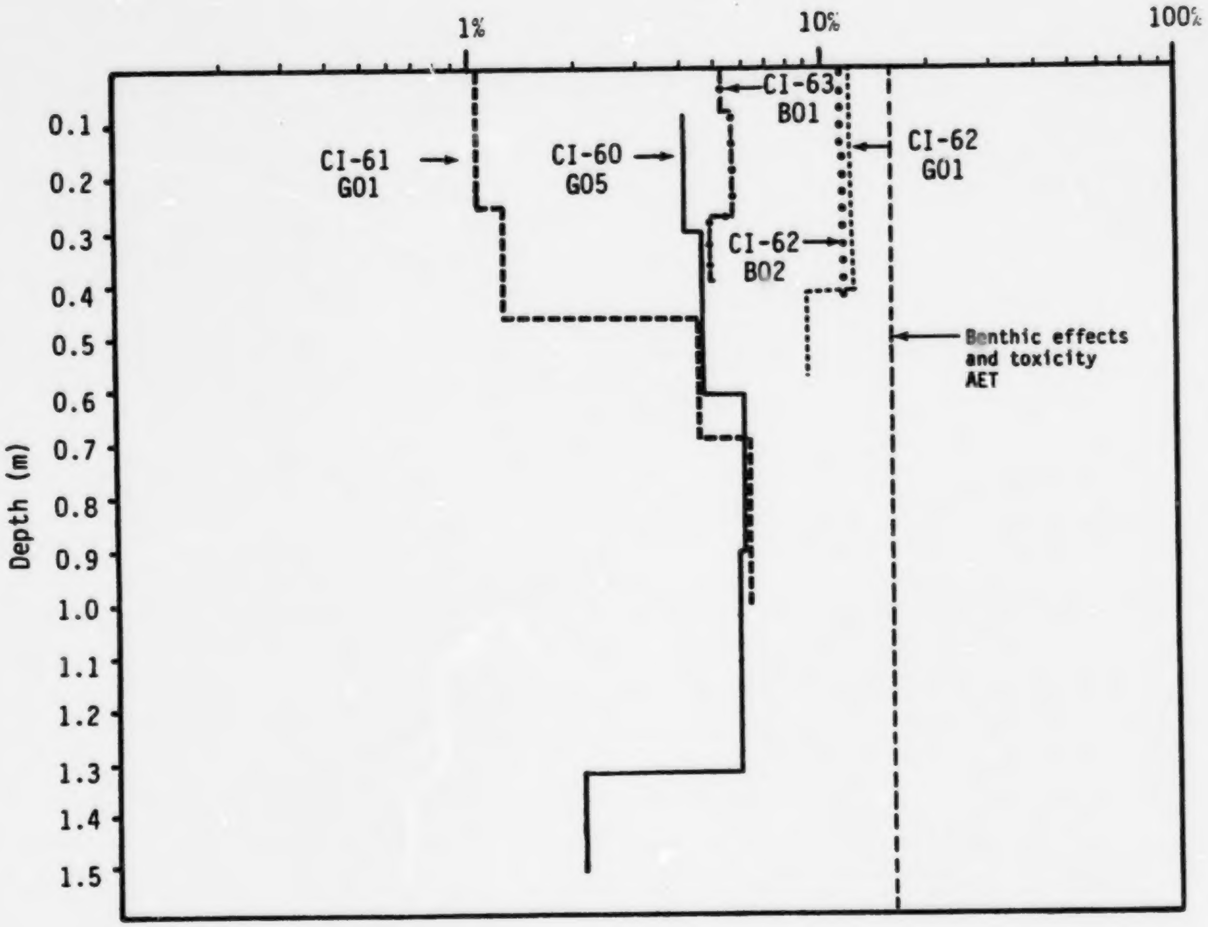


Figure 7.6.6

PERCENTAGE OF TOTAL ORGANIC CARBON
WITH DEPTH IN SEDIMENTS OF CITY WATERWAY
(For station locations refer to Figure 7.6.3)

1.6 ft (0.5 m) to concentrations corresponding to those observed in other City Waterway cores. This increase suggested that current organic carbon discharges to the lower waterway are considerably less than historical discharges. Alternatively, substantial dilution of the organically enriched material accumulating elsewhere in City Waterway may now occur in the lower City Waterway where it may not have in the past.

7.6.3.2 Loading Estimates--

The chemical oxygen demand (COD) of discharges to City Waterway provides the only means available to estimate the relative contribution of these discharges to the total organic carbon content of waterway sediments. COD can be empirically related to the BOD, organic carbon, or organic matter content of the source (American Public Health Association et al. 1981). Johnson and Norton (1984c) summarized all COD data available in City Waterway storm drains (Table 7.6.2). The south Tacoma drain (CS-237) and the Wheeler-Osgood drain (CW-254) each contributed 35 - 37 percent of the quantified COD loading to the City Waterway/Wheeler-Osgood Waterway system. The COD data for the Wheeler-Osgood drain are highly suspect due to interference from the presence of saltwater.

The only NPDES-permitted discharger to City Waterway whose permit specifically addresses BOD or COD is Hygrade Foods (Permit WA9002078-8, expired 7/8/80). This firm discharges runoff and noncontact cooling water to the Wheeler-Osgood Waterway. Although process effluents are not to be discharged to the waterway, this has reportedly occurred as a result of unidentified cross-connections between the cooling water and process sewer (WDOE Hygrade files). Other industries are permitted to discharge oil and grease, which would contribute to TOC loading. They include Fick Foundry (Permit WA0037851), Shell Oil (WA0001210), Union Oil (WA0000728), Atlas Foundry (WA0022918), and Mobil Oil (WA0003387). Western Fish and Oyster Company has an NPDES permit (WA0022853) to discharge screened process wastewater to City Waterway. The firm is not required to monitor for BOD, but it is probably not a major source of organic carbon based on the low discharge volume.

7.6.3.3 Source Identification--

From the turn of the century to the 1970s, City Waterway was one of the main recipients of wastes from combined sewer outfalls in the Tacoma area. As of 1950, there were six untreated sewage outfalls entering the waterway, serving an area of about 11,000 ac and more than 60,000 people. In addition, untreated industrial effluent entered via these sewers (Orlob et al. 1950). Locations of the six outfalls included two outfalls at the head of the waterway (now called the Nalley Valley and south Tacoma drains); the 11th Street, 15th Street, and 21st Street drains; and a drain at the head of Wheeler-Osgood Waterway. In addition to domestic sewage, these sewers probably carried wastes from Nalley's Foods, Model Pickle Company, Fassett and Company, Tacoma Vegetable Oils, Copes Poultry, and several dairies. The total estimated BOD loading from these industries alone in 1950 was greater than 1,000 lb/day (Jones 1951; based on a population-equivalent

Table 7.6.2

COD: SUMMARY OF LOADINGS FROM DISCHARGES TO CITY WATERWAY

Drain #	Drain Name	Flow (MGD) (Avg. and Range) (# of Observations)	Period of Observations for Contaminant Concentrations	Concentration (ug/l) (Avg. and Range) (# of Observations)	Loading (lbs/day) (Avg. and Range)
CW-254	Wheeler-Osgood Drain, 30-inch Steel Pipe	0.29 (0.13-0.63) (n=4)	7/28/81-3/29/82	330,000 (170,000-490,000) (n=2)	800 (410-1,200)
CS-237	South Tacoma Drain	4.8 2.58-10.98 (n=4)	7/28/81-2/16/81	19,000 (4,000-33,000) (n=2)	760 (160-1,300)
CN-237	Nalley Valley Drain	3.6 1.2-10.66 (n=8)	7/28/81-2/16/82	11,000 (4,000-18,000) (n=2)	330 (120-540)
CI-230	15th Street Drain 48-inch Concrete Pipe	0.17 (0.14-0.22) (n=3)	4/28/82	190,000 --- (n=1)	270

Note: The data for the Wheeler Osgood drain (CW254) are highly suspect due to interference from the presence of saltwater.

of greater than 5,000). This estimate probably did not reflect the total discharge via sewers from food processors in this service area, since Jones (1951) did not specify outfall locations for many industries except to comment that they discharge to "City Sewer." The size of the area discharging to City Waterway makes it probable that a number of additional food processors ultimately discharged to the waterway via the sewer system.

As a consequence of the volume and nature of the wastes historically discharged to City Waterway, the environmental quality of the waterway had badly deteriorated by the mid-1900s. Orlob et al. (1950) described the condition of the waterway at the time as follows:

> The condition of the waterway as a result of the sewage discharge from these sewers and the added industrial waste effluents, particularly that of a large meat packing plant, has long been a source of embarrassment to many of Tacoma's residents and has given rise to numerous complaints in recent years. Since the only water entering the waterway is either in the form of sewage or industrial waste and there is little exchange of water due to tidal action, the area so affected amounts to little more than a septic pool, the bottom of which is covered with organic deposits devoid of any life and in which fish either could not or do not choose to live.

Improvement in the environmental quality of City Waterway occurred in the late 1960s when efforts were made to reroute the sanitary and industrial wastes from City Waterway to the Central Treatment Plant (Kennedy Engineers 1969; O'Dell, C., personal communication). Because of cross-connections between the sanitary and storm sewers, sewage contamination of the Nalley Valley drain continued until 1979, when an interceptor was installed at 23rd and B Streets. Tacoma Sewer Utilities believes that installation of this interceptor has corrected the problem of sewage in the discharge of the Nalley Valley drain (O'Dell, C., personal communication). In 1982, the WDOE found that fecal coliform bacteria concentrations in the discharge far exceeded those of any other drain to the waterway (1,800 - 14,000/100 mL; Johnson and Norton 1984b). These fecal coliform bacteria may reflect contamination by domestic sewage or simply domestic animal (e.g., pet) waste in stormwater runoff.

Several fish processors (Northern Fish Products, Marush Fish and Oyster Company, and possibly National Fish and Oyster Company) along Dock Street dumped wastes directly into City Waterway (Jones 1951). By 1979, Western Fish and Oyster Company, at 1137 Dock Street, was the only company permitted to discharge screened process water and washwater directly to the waterway (NPDES Permit WA0022853).

A major historical source of total organic carbon to Wheeler-Osgood Waterway was Carsten's Packing Company. A slaughtering/packing plant, the firm's only treatment of process wastes consisted of grease skimmers, and they were inadequate. The estimated BOD loading from this discharge alone was 8,800 lb/day based on a population equivalent of 44,000 (Jones

1951). The facilities were leased to Hygrade Foods about 1955 and bought by Hygrade about 1960. Discharge of all process wastes to Wheeler-Osgood Waterway continued until 1970, when the process wastes were rerouted to the Tacoma Central Sewage Treatment Plant (O'Dell, C., personal communication). As a result of unidentified cross-connections, some process wastes continued to be discharged to Wheeler-Osgood Waterway along with cooling water and runoff through the mid-1970s. At the present time, the firm has an NPDES permit for discharge of runoff and noncontact cooling water to Wheeler-Osgood Waterway.

7.6.3.4 Summary and Recommendations--

Six discharges are known to have been major sources of organic carbon to City and Wheeler-Osgood Waterways. Only two or three (Nalley Valley and/or south Tacoma, Wheeler-Osgood) are implicated as major sources by the spatial pattern of organic enrichment in surficial sediments. Source identification efforts have been directed at these discharges. Both the Nalley Valley and south Tacoma drains discharged untreated sewage to the head of City Waterway through 1969. Significant quantities of sewage were discharged from the Nalley Valley drain until 1979. One or both of these drains is responsible for the increase in organic enrichment in surficial sediments from the mouth to the head of City Waterway.

The Wheeler-Osgood drain is believed to be a major source of the organic enrichment noted in the surficial sediments of Wheeler-Osgood Waterway. The Wheeler-Osgood drain historically discharged untreated sewage and process wastes from Carsten's Packing Company and Hygrade Foods. Discharge of organic material from this drain should have been substantially reduced in 1969-1970 with the diversion of process wastes and sewage to the Tacoma Central Sewage Treatment Plant. However, some discharge of process wastes continued until the mid-1970s because of unidentified cross-connections between process and storm sewers.

Although the drains noted above had been major sources of organic material, it is difficult to determine the extent to which they serve as ongoing sources of organic material to City and Wheeler-Osgood Waterways. Discharge of significant amounts of organic material from these drains should have ceased in the 1970s, yet organic enrichment of 9 - 18 percent total organic carbon was apparent in surficial sediments. Similar elevations in organic carbon concentrations were not apparent at the outfalls of other storm drains in the tideflats area. In addition, the sediment cores at the head of City Waterway and in Wheeler-Osgood Waterway showed no evidence of any reduction in the rate of organic carbon input over time, although a decrease was expected given the discharge history of the major drains. Decaying wood and vegetation in the stagnated Wheeler-Osgood Waterway may contribute to the substantial organic enrichment observed.

Sediment accumulation rates in City and Wheeler-Osgood Waterways could be used to evaluate 1) if possible slow sedimentation in these areas has resulted in minimal burial of historically contaminated sediments, or 2) if relatively rapid sedimentation has occurred indicating an ongoing source to account for continued high levels of organic enrichment. No site-specific estimates of these rates have been made for these waterways. Based on sampling throughout Puget Sound (Riley 1981; Crecelius 1983; Carpenter in press), 1 cm/yr may be used as a crude approximation of a typical surface sedimentation rate. It is recognized that sediment accumulation rates in City and Wheeler-Osgood Waterways may be very different from sediment accumulation rates in Puget Sound, and may differ even between the two areas. Assuming an accretion rate of 1 cm/yr, approximately 6 cm of sediment may have been deposited since the last known major discharge of organic material in 1979. In any event, if deposition rates in City Waterway are comparable to or greater than those in other areas of Puget Sound, adequate time should have elapsed to bury organic-rich sediments beneath sediments of lower organic content provided the major input of organic carbon actually ceased in or before 1979 and no major disturbances of the sediments has occurred.

The fact that organic enrichment is observed in surficial sediments (upper 2 cm) suggests two possibilities: (1) burial of enriched sediments in City Waterway, or particularly Wheeler-Osgood Waterway, is slower than predicted or (2) significant discharge of organic carbon from the Nalley Valley or south Tacoma drains to City Waterway has continued beyond 1979 and a current source of organic carbon (possibly natural) exists in Wheeler-Osgood Waterway. Available data are not adequate to determine conclusively which of these two explanations is correct. The data indicate that discharges of organic material from the Nalley Valley or south Tacoma drains persist. This conclusion is supported by the fact that each of the two major storm drains had a flow of about 4 MGD and a total suspended solids loading of about 7,000 lb/day (Table 7.6.2, Johnson and Norton 1984c). Moreover, as recently as 1982, the Nalley Valley drain was found to have fecal coliform bacteria concentrations up to 15 times greater than those in any other storm drain discharging to City Waterway.

Investigations should be undertaken to determine the origin of the organic carbon in the Nalley Valley and south Tacoma drains. Investigations into organic carbon sources to these drains should include analyses for chemical/biological indicators of sewage contamination (e.g., coprostanol, fecal coliform bacteria). The Wheeler-Osgood drain should be investigated as a source of organic material. Natural sources of organic enrichment in Wheeler-Osgood should also be considered.

7.6.4 Aromatic Hydrocarbons and Dibenzofuran

7.6.4.1 Spatial Distribution--

HPAH, LPAH, and dibenzofuran were identified as preliminary contaminants of concern in City Waterway. Concentrations of HPAH and LPAH exceeded AET in some sediments from several areas of the waterway. LPAH concentrations ranged from 500 to 21,000 ug/kg dry weight in City Waterway; most concentrations were less than 5,000 ug/kg dry weight (Figure 7.6.7). Concentrations of HPAH ranged from 4,700 to 82,000 ug/kg dry weight; most concentrations were less than 20,000 ug/kg dry weight (Figure 7.6.8).

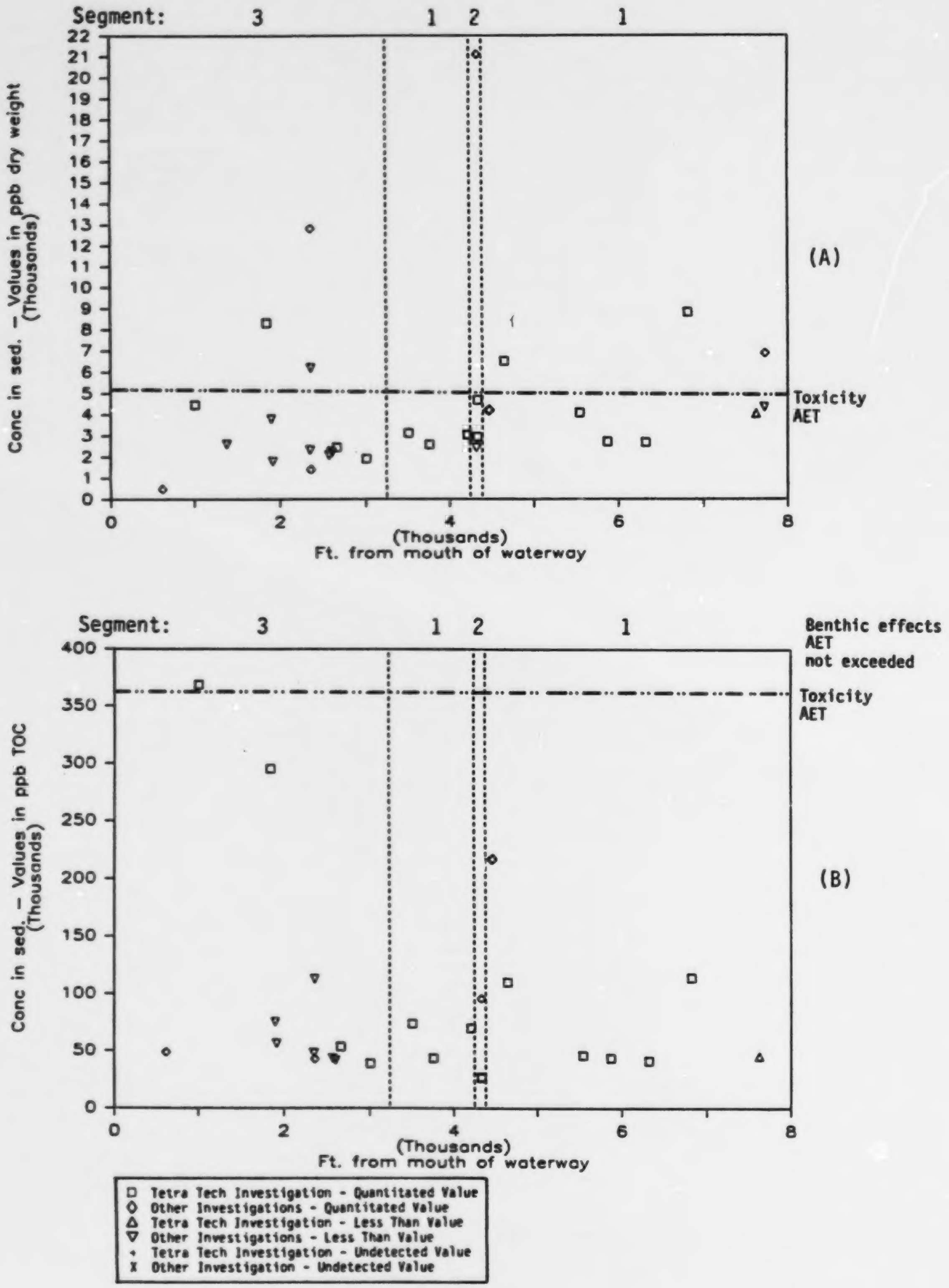


Figure 7.6.7

SURFICIAL SEDIMENT CONCENTRATIONS OF LPAH
IN CITY WATERWAY, (A) DRY WEIGHT BASIS, (B) NORMALIZED
TO TOTAL ORGANIC CARBON

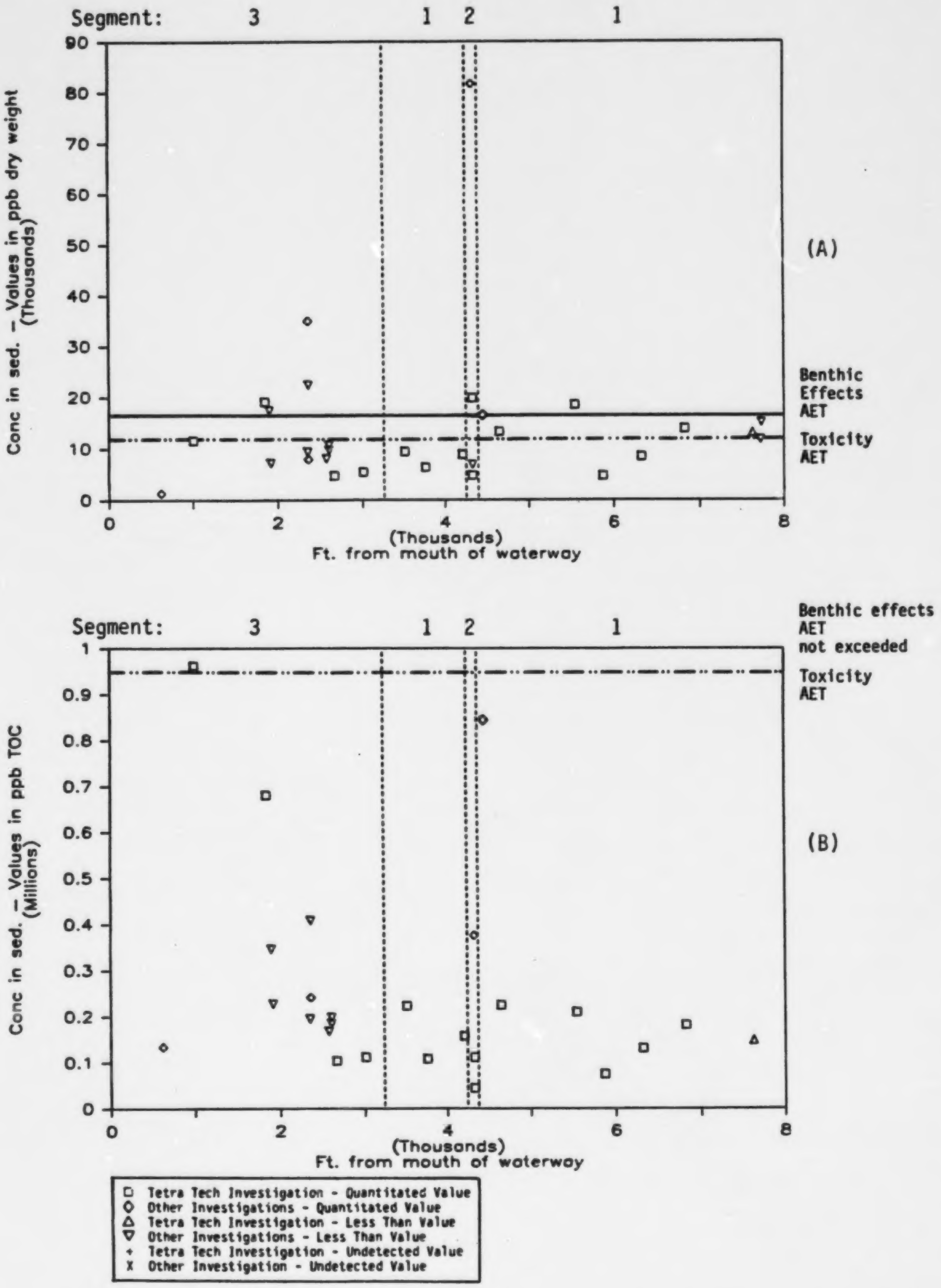


Figure 7.6.8

SURFICIAL SEDIMENT CONCENTRATIONS OF HPAH
IN CITY WATERWAY, (A) DRY WEIGHT BASIS, (B) NORMALIZED
TO TOTAL ORGANIC CARBON

Sediments from a single station in the middle of Wheeler-Osgood Waterway (sampled by the U.S. EPA; Swartz et al. 1982) contained LPAH and HPAH at concentrations (dry weight) several times greater than those at any other site sampled within the waterway. A second sample collected by U.S. EPA near the head of Wheeler-Osgood Waterway (see Figure 7.6.3) was approximately one tenth as contaminated. However, LPAH concentrations normalized to organic carbon were three times higher near the head than at any of the stations in the middle of Wheeler-Osgood Waterway (Figure 7.6.7b). These data suggest a source of LPAH near the head of the waterway to account for the highest proportion of LPAH to total organic carbon, but much greater accumulation of contaminated, organic-rich sediments in portions of the middle of the waterway. There was no obvious gradient in HPAH concentrations after normalization to organic carbon.

In the main channel of City Waterway, LPAH and HPAH concentrations normalized to organic carbon were approximately five times higher in sediments near the mouth of the waterway than the average in sediments elsewhere (Figures 7.6.7 and 7.6.8). These data suggest a source of PAH in addition to transport of contaminated organic material from drains at the head of City Waterway. The PAH source appears to be localized near the mouth of the waterway. Because the highest PAH concentrations (when normalized to organic carbon) were found in mid-channel sediments rather than in nearshore sediments (i.e., the eastern shoreline sampled by WDOE), there is little evidence of a direct link to a PAH source on the adjacent shoreline.

No other sites in City Waterway had significantly elevated sediment concentrations of LPAH or HPAH. With the exception of the waterway mouth, PAH concentrations throughout the main channel of City Waterway were relatively uniform, with no evidence to suggest proximity to a dominant PAH source.

Spatial and depth trends of dibenzofuran concentrations resembled those of LPAH in City Waterway on both a dry-weight and organic carbon-normalized basis. Surface sediment concentrations ranged from 30 to 450 ug/kg dry weight (340 to 14,000 ug/kg TOC). This correlation with LPAH was found throughout the tideflats.

The vertical patterns of sediment contamination by LPAH were similar throughout the waterway, with somewhat elevated concentrations at depth (Figure 7.6.9). PAH concentrations in both composited intervals of the core from Wheeler-Osgood Waterway were higher than that observed in 0-2 cm sediments from the same area. A subsurface maximum in PAH concentrations has been observed in other sediment cores in central Puget Sound and is likely related to greater PAH discharges in past years (Crecelius and Bloom in review; Barrick and Prahl in review). The cores at the head and near the mouth of the waterway (Stations CI-60 and CI-61) showed similar LPAH profiles. The vertical pattern of sediment contamination by HPAH (Figure 7.6.10) was similar to that of LPAH, except for CI-61. The lowest horizon of this core had proportionately more LPAH than HPAH in comparison with other horizons within this core.

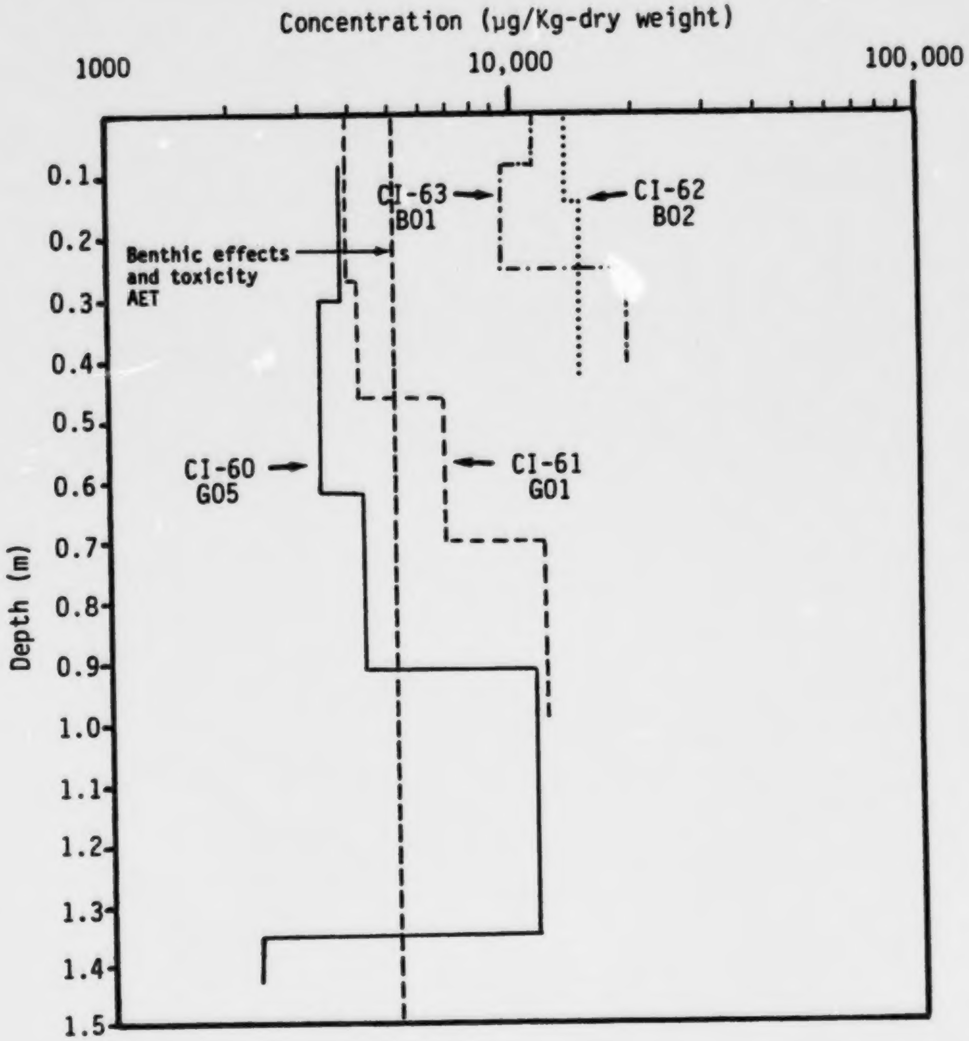


Figure 7.6.9

CONCENTRATION OF TOTAL LPAH ON A DRY WEIGHT BASIS
WITH DEPTH IN SEDIMENTS OF CITY WATERWAY
(For station locations refer to Figure 7.6.3)

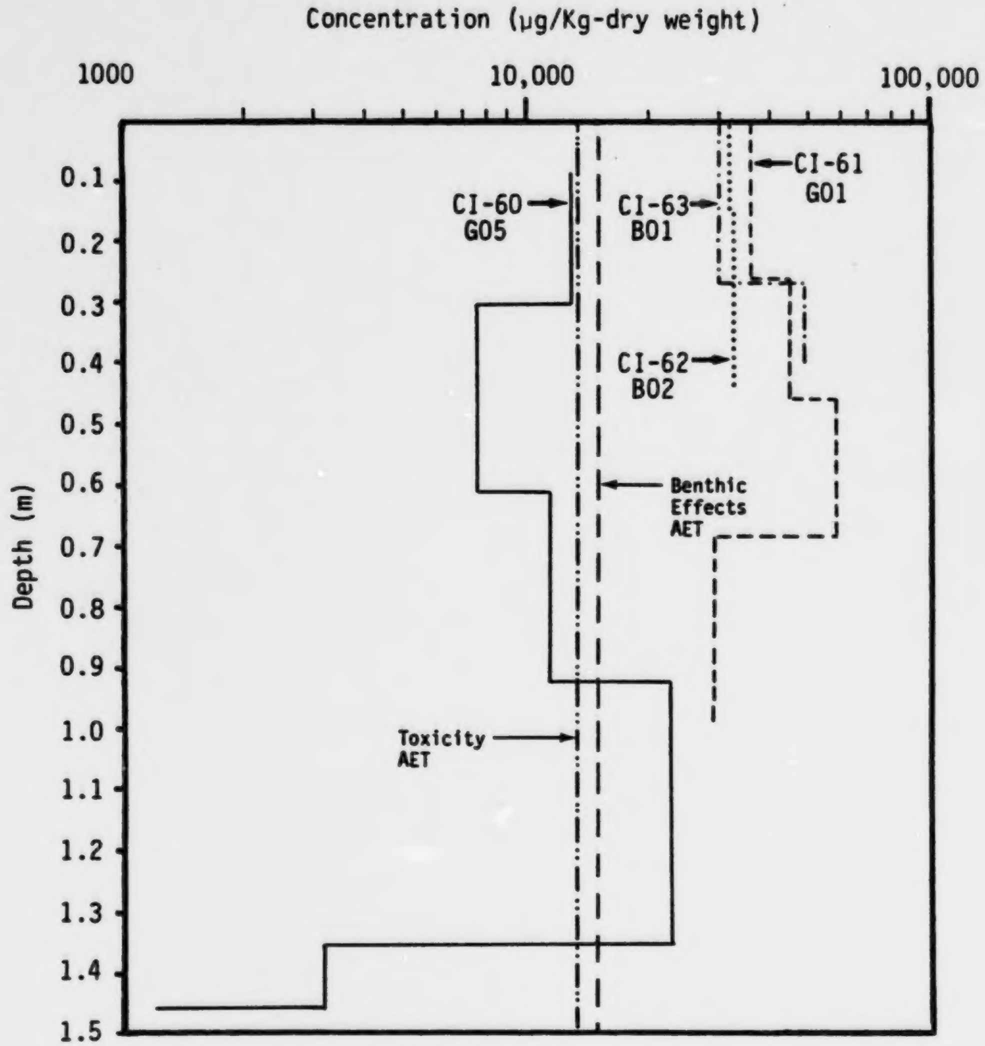


Figure 7.6.10

CONCENTRATION OF TOTAL HPAH ON A DRY WEIGHT BASIS
WITH DEPTH IN THE SEDIMENTS IN CITY WATERWAY
(For station locations refer to Figure 7.63)

Relative abundance of HPAH to LPAH in sediment cores was compared to discriminate discharges by various sources over time. The results are shown in Table 7.6.3. Except for sediment core CI-61 (Segment 3), the ratios of HPAH to LPAH were similar in magnitude to those in surficial sediments measured in the Tetra Tech survey. The aromatic hydrocarbons in the subsurface sediments at CI-61 showed a much higher abundance of HPAH relative to LPAH at this site, potentially indicating a historical combustion source of HPAH or dumping of combustion products in this vicinity.

7.6.4.2 Loading Estimates--

Aromatic hydrocarbons have seldom been detected in storm drain discharges around City Waterway with detection limits ranging from 0.1 to 1 ug/l. None of the storm drains with detectable levels of LPAH and HPAH showed consistent contamination. Naphthalene, anthracene, and phenanthrene of the LPAH, and pyrene, fluoranthene, and benzo(g,h,i)perylene of the HPAH were the only compounds measured in any drain (Tables 7.6.4 and 7.6.5). Based solely on the limited data available, the 15th Street drain appears to be the largest source of PAH among the discharges considered. Only the Nalley Valley drain (CN-237) has been analyzed for dibenzofuran. None was detected (detection limits were 0.1 and 0.3 ug/L).

7.6.4.3 Source Identification--

The surficial sediment chemistry data suggest a source of both LPAH and HPAH near the mouth of City Waterway. The sediment core data from the mouth of the waterway indicate that sources of PAH have historically had a greater proportion of HPAH relative to LPAH than do ongoing sources. Three potential historical sources of these HPAH have been identified: (1) marina fires, (2) Fick Foundry, and (3) Woodworth and Company. Data were inadequate to demonstrate with certainty that these were the major sources of contamination. In addition, PAH contamination in surficial sediments suggests an ongoing source and the three identified above are all historical.

Johnson and Norton (1984b) have suggested that fires may be responsible for elevated HPAH concentrations in sediments near the mouth of City Waterway. There were two major dock fires near the mouth of City Waterway in the 1970s (Mork, S., personal communication). There have been no fires in the area in at least the past 6 yr.

Fick Foundry is located near the mouth of City Waterway along the eastern shore. At present, the firm uses natural gas to fire its furnaces. However, it was not determined during these investigations if this has always been the case. Past use of coal or heavy fuel oil could have been a source of HPAH.

Woodworth and Company own property on the east shore of City Waterway at the foot of the 11th Street bridge. Prior to 1977-1978, the firm operated an asphalt plant with a wet scrubbing system to reduce atmospheric emissions. Discharge from the wet scrubbing system was routed to a settling pond and

Table 7.6.3

RATIO OF HIGH MOLECULAR WEIGHT PAH TO LOW MOLECULAR WEIGHT PAH WITH DEPTH IN THE SEDIMENTS OF CITY WATERWAY

Station	Location	Horizon	Ratio
CI-60 (G05)	Segment 1 - Head of the waterway, approx. 7,600 ft from mouth	H1	3.4
		H2	2.3
		H3	2.7
		H4	2.0
		H5	1.3
CI-63 (B01)	Segment 1 - Approx. 4,600 ft from mouth	H1	2.8
		H2	3.1
		H3	2.6
CI-62 (B02)	Segment 2 - Wheeler-Osgood	H1	2.3
		H2	2.3
CI-62 (G01)	Segment 2 - Wheeler-Osgood	H1	1.9
		H2	1.4
CI-61 (G01)	Segment 3 - Approx. 3,500 ft from mouth	H1	9.2
		H2	11
		H3	8.7
		H4	2.4

Table 7.6.4

LOW MOLECULAR WEIGHT PAH: SUMMARY OF LOADINGS FROM DISCHARGES TO THE CITY WATERWAY

Drain #	Drain Name	Flow (MGD) (Avg and Range) (# of Observations)	Period of Observations for Contaminant Concentrations	Concentration (µg/l) (Avg and Range) (# of Observations)	Loading (lbs/day) (Avg and Range)	Compounds Detected
CI-230	15th St. Stormdrain, 48" Concrete Pipe	0.17 (0.14-0.22) (n=3)	4/28/82,9/7/83	L 31 (18-60) (n=2)	L 0.44 (0.0026-0.085)	Naphthalene, Phenanthrene
CN-237	Nalley Valley Drain	3.6 (1.2-10.66) (n=8)	7/28/81,no date	L 5.2 (0.4-10) (n=2)	L 0.16 (0.012-0.30)	Naphthalene, Anthracene
CS-237	South Tacoma Drain	4.8 (2.58-10.98) (n=4)	7/28/81	L 0.4 --- (n=1)	L 0.016 ---	Phenanthrene
CW-254	30" Steel Stormdrain E. End of Wheeler-Osgood Waterway	0.29 (0.13-0.63) (n=4)	3/29/82	15	0.036	Anthracene/ Phenanthrene (combined)

L = Less Than

NOTE: Low molecular weight PAH have been analyzed for, but not detected in, the following drains: CI-225(1), CI-234(1), CI-243(1), CI-245(1), CI-248(1), and CI-703(1). The number in parentheses represents number of analyses. Detection limits in all cases ranged from 0.1 to 1 µg/l.

Table 7.6.5

HIGH MOLECULAR WEIGHT PAH: SUMMARY OF LOADINGS FROM DISCHARGES TO THE CITY WATERWAY

Drain #	Drain Name	Flow (MGD) (Avg and Range) (# of Observations)	Period of Observations for Contaminant Concentrations	Concentration (ug/l) (Avg and Range) (# of Observations)	Loading (lbs/day) (Avg and Range)	Compounds Detected
CI-230	15th St. Stormdrain, 48" Concrete Pipe	0.17 (0.14-0.22) (n=3)	9/7/83	L 0.6 --- (n=1)	L 0.00085 ---	Fluoranthene, Pyrene, Benzo-(g,h,i)Perylene
CI-234	24" Wood Box Outfall at S. 21st Street	0.034 (0.03-0.037) (n=2)	9/7/83	L 0.2	L 0.00057	Pyrene
CI-245	18" Concrete Pipe Stormdrain from RR Yard	0.070 (0.05-0.09) (n=2)	9/7/83	L 0.2	L 0.00012	Pyrene

L = Less Than

NOTE: The following discharges have been sampled and found not to contain high molecular weight PAH (numbers in parentheses indicate number of analyses and detection limits): CI-225 (1, 0.1 ug/l); CI-243 (1, 0.1 ug/l); CI-248 (1, 0.1 ug/l); CI-703 (1, 0.1 ug/l); CN-237 (5, 0.1 ug/l); CS-237 (2, 0.1-10 ug/l); and CW-254 (3, 0.1-10 ug/l).

a flocculent was added to promote settling. Solids were retained for land disposal (site not established) and the overflow was discharged to City Waterway (NPDES Permit WA0001368).

Investigations of the D Street petroleum storage facilities have been conducted by Johnson and Norton (1984b) and Hart-Crowser and Associates (1982). The tank farms in this area of the waterway store leaded gasoline, unleaded gasoline, and diesel fuel. Examination of groundwater has shown contamination resembling these products and seepage of product from the banks along the waterway. At high tide, this seepage is submerged and the product bubbles to the surface creating a sheen. The contaminants involved probably reach City Waterway sediments, but most undergo volatilization and some dissolution because the product is dominated by one- and two-ring compounds. The sediments off the D Street facilities were dominated by four- and five-ring compounds, suggesting that the D Street facilities was not a major source of LPAH or HPAH observed in the sediments.

In the upper waterway, the major storm drains are all confirmed PAH sources, as demonstrated by the loading estimates. The presence of PAH in these discharges is not surprising, given that the compounds are typical constituents in urban runoff (Barrick 1982; Galvin and Moore 1982). The sediment core data from Station CI-60 at the head of the waterway suggest a historical source, possibly related to the coal gasification site at 23rd and A Streets (Tacoma Spur) that closed in 1926. According to Hart-Crowser and Associates (1984), this site continues to contribute about 0.22 lb/day of total aromatic hydrocarbons to City Waterway via shallow groundwater input. These investigators indicated that there were other possible sources of groundwater contamination in this area, including an abandoned gasoline station at Puyallup and A Streets, a coal- and wood-fired power generating station, a machinery and equipment storage yard, and source petroleum product storage tanks east of the waterway. PAH contamination has been found in soils beneath all but the power generating plant site. This site was discovered while routine soil borings were being taken for the SR-705 highway project.

The Tar Pits site is another potential source of PAH to Wheeler-Osgood and City Waterways. The site consists of a group of scattered and undefined ponds filled with liquid tar. The material is a waste product of a coal gasification plant that operated on the site from 1924 to 1950. A sample of the tar was analyzed and it was determined to contain four percent PAH. Two additional sources of LPAH were discovered near the head of City Waterway. One was in the vicinity of West Coast Grocery and the other was near 15th Street. Petroleum product was collecting in storm drains near West Coast Grocery and discharging to City Waterway via CI-248. The source of the petroleum product (oils) is unknown but may be associated with the historical operation of a railroad roundhouse in this area. Petroleum product (gasoline) was discovered by the Washington State Department of Transportation (WDOT) on the west side of City Waterway near 15th Street during field investigations for the proposed freeway right-of-way. The source of the gasoline is unknown but WDOE identified four gasoline stations in the vicinity that are over 20 yr old (Pierce, R., 2 August 1985, personal communication). The Chevron facility may also be a potential source of LPAH to Wheeler-Osgood and City Waterways.

Two sources of PAH to the waterway that could not be adequately assessed with existing data are spills and atmospheric deposition. Spills and other unauthorized discharges could represent a significant source of LPAH to City Waterway, although most would be volatilized or degraded. A review of recent WDOE spill records indicated that from 1979 to 1985, 3,500 - 4,000 gal of diesel, gasoline, or other petroleum products were released into the water column of City Waterway. This does not include unreported spills or discharge of PAH from activities such as bilge pumping, a practice made illegal in the mid-1970s.

Atmospheric deposition is a potential route of PAH migration to the waterway, particularly for HPAH. The importance of this route can only be partially assessed because the Puget Sound Air Pollution Control Authority (PSAPCA) does not collect data on PAH concentrations of airborne particulates. The potential surface area available for direct deposition of particles in the waterway is much less than that on land. Most of the PAH released to the atmosphere would be expected to reach the waterways by surface runoff, and therefore, should be accounted for in PAH loading estimates for the drains. However, the largest concentration of PAH-contaminated material can be expected to be discharged from the storm drains during the early stages of a rainfall event, a period for which little contaminant monitoring data exist. This may help explain why HPAH have been undetected in several analyses of the storm drains.

Sources of dibenzofuran are unknown. Judging from the similarity between dibenzofuran and PAH distributions in sediments, the same sources are probably involved.

7.6.4.4 Summary and Recommendations--

The sources of LPAH and HPAH to the City Waterway are not well defined. Several possible sources include:

- Storm drains - Based on the available loading data, the storm drains are confirmed sources of LPAH and HPAH.

- D Street petroleum facilities - The petroleum storage facilities on the east shore of City Waterway are known to be a source of PAH to the waterway via groundwater as a result of past spills and product leakage. However, the PAH contributed by these facilities are dominated by one- and two-ring compounds that do not persist in waterway sediments.

- Fick Foundry, Woodworth and Company, and marina fires - These are suggested as potential past sources of HPAH to City Waterway sediments.

- Several facilities near the intersection of 23rd and A Streets - Past facilities, including a coal gasification plant, are potential historical sources of LPAH and/or HPAH and ongoing sources of LPAH via groundwater, (i.e., the Tar Pits site and the Tacoma Spur).
- Unknown sources of LPAH near the head of City Waterway - Potential ongoing sources include Chevron, and unknown sources near West Coast Grocery and 15th Street.
- General - Release of petroleum products from marinas, boats, spills are potential sources.

LPAH and HPAH sources in Segment 3 near the mouth of City Waterway need to be further explored. Properties along both sides of the waterway should be inspected in order to identify potential sources. Additional sediment sampling in the waterway may be valuable, particularly along the western shore near the mouth, because all presently available data in this area are limited to the central channel or eastern shore.

7.6.5 Dichlorobenzenes

7.6.5.1 Spatial Distribution--

Dichlorobenzenes were preliminary contaminants of concern in both City and Wheeler-Osgood Waterways. In City Waterway, concentrations of total dichlorobenzenes ranged from 47 to 400 ug/kg dry weight (600 to 3,300 ug/kg TOC), with an overall decrease in concentration from the head to the mouth of the waterway. The distribution of 1,4-dichlorobenzene is shown in Figure 7.6.11. No historical data for 1,4-dichlorobenzene are available.

The highest concentration of 1,4-dichlorobenzene normalized to both dry weight and TOC was found at the head of City Waterway (Station CI-11). A second maximum of 1,4-dichlorobenzene concentrations (dry weight) was observed in the Wheeler-Osgood Waterway. Dry-weight concentrations decreased in the main waterway in both directions from the juncture with Wheeler-Osgood Waterway. A similar trend was observed when concentrations were normalized to organic carbon content (Figure 7.6.11), except that there was more scatter in the data and a relatively high concentration of 1,4-dichlorobenzene near the mouth of City Waterway (Station CI-22). After normalization to organic carbon, 1,4-dichlorobenzene concentrations in Wheeler-Osgood Waterway were lower than those in the main portion of City Waterway. This relative difference suggests that a major source of 1,4-dichlorobenzene to City Waterway in this area was along the main waterway rather than within Wheeler-Osgood Waterway.

1,2-Dichlorobenzene concentrations were elevated in Wheeler-Osgood Waterway only when normalized to dry weight or organic carbon content (Figure 7.6.12). These data suggest a localized source of contamination that did not affect the main channel of City Waterway. One possible explanation

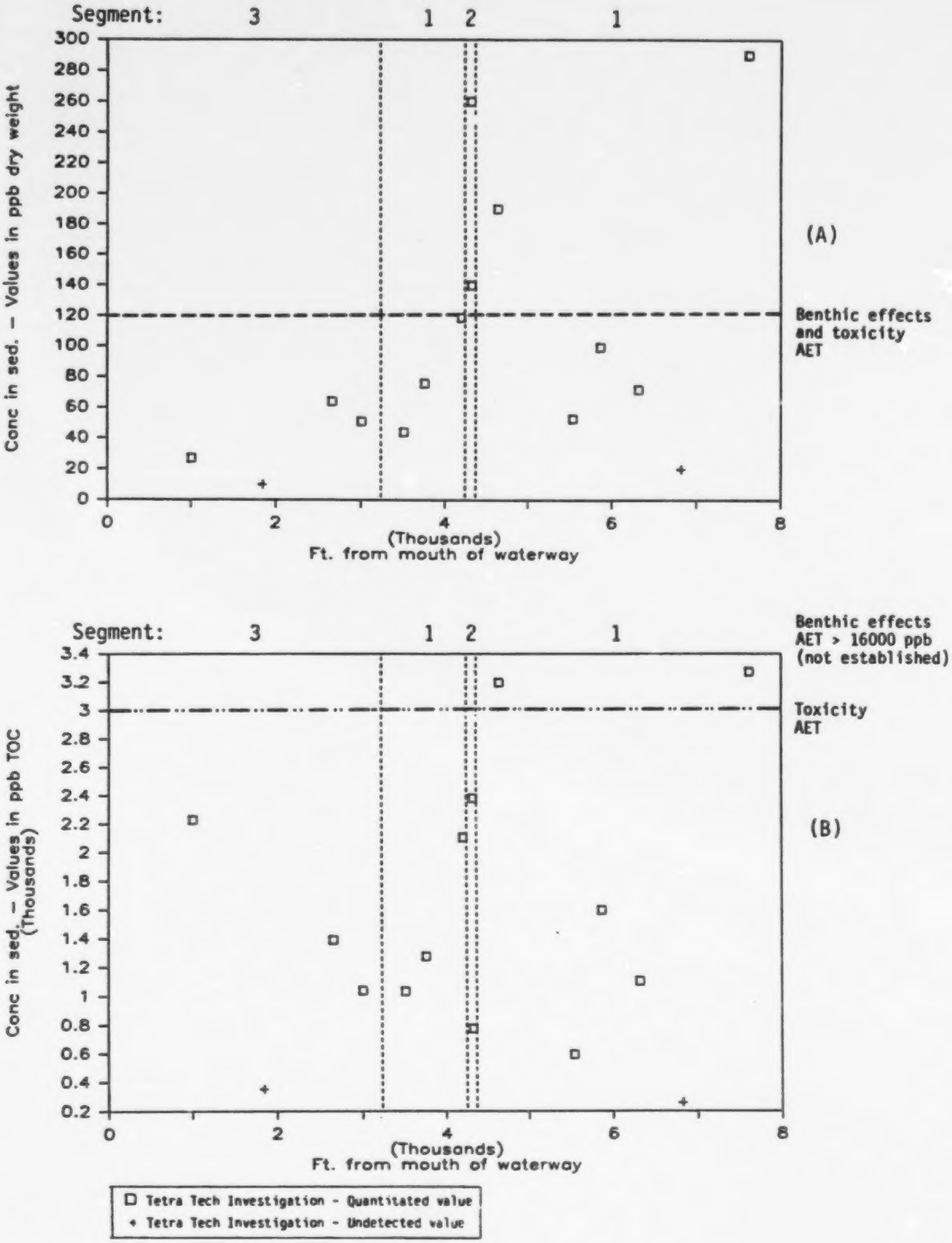


Figure 7.6.11

SURFICIAL SEDIMENT CONCENTRATIONS OF 1,4-DICHLOROBENZENE IN CITY WATERWAY, (A) DRY WEIGHT BASIS, (B) NORMALIZED TO TOTAL ORGANIC CARBON

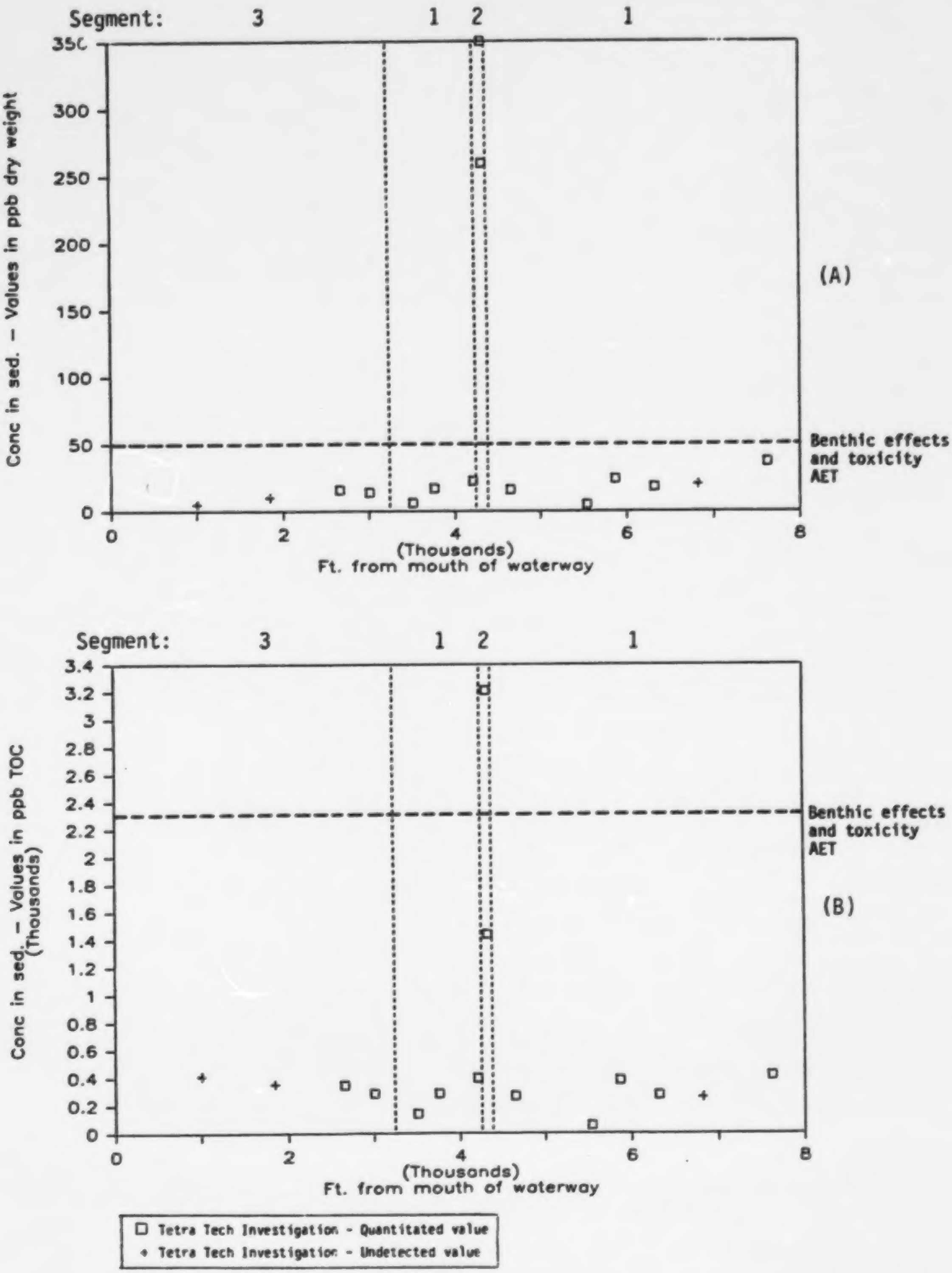


Figure 7.6.12

SURFICIAL SEDIMENT CONCENTRATIONS OF 1,2-DICHLOROBENZENE IN CITY WATERWAY, (A) DRY WEIGHT BASIS, (B) NORMALIZED TO TOTAL ORGANIC CARBON for the substantially different distributions of these two dichlorobenzene isomers is that 1,4-dichlorobenzene is transported from a source in City Waterway to sediments in Wheeler-Osgood Waterway but that 1,2-dichlorobenzene from a source in Wheeler-Osgood Waterway is not transported in the opposite direction. A second, and perhaps more likely, explanation is that there is little transport between the two waterways in either direction because of a sill at the entrance of Wheeler-Osgood Waterway and that independent sources of dichlorobenzenes (one enriched with 1,2-dichlorobenzene in Wheeler-Osgood Waterway) contribute to the contamination observed in each area.

In summary, there are distinctive differences in the composition of chlorinated benzene contamination in City and Wheeler-Osgood Waterways. In Wheeler-Osgood Waterway (City Waterway Segment 2), a major source of 1,2-dichlorobenzene is indicated, although 1,4-dichlorobenzene is also present in smaller concentrations. In the main portion of City Waterway, two sources of 1,4-dichlorobenzene are indicated when concentrations were normalized both to dry weight and organic carbon content: (1) at the head of the waterway, and (2) at about 4,700 ft from the mouth. A third source near the waterway mouth is suggested on the basis of organic carbon-normalized concentrations.

The vertical patterns of contamination in sediment core samples from City Waterway are shown in Figure 7.6.13. For 1,4-dichlorobenzene, the dissimilarity of the vertical contamination gradients among the cores indicates that historically there was more than one source of the compound, and that discharges have not been uniform throughout the waterway. At the head of the waterway (Station CI-60), concentrations of 1,4-dichlorobenzene increased over time, reached a maximum during the period represented by deposition of the second horizon (0.3-0.6 m), and since that period have decreased. This same vertical pattern of contamination was not apparent in a core taken in the lower one-third of the waterway (Station CI-61).

In Wheeler-Osgood Waterway (0.5-m core, Station CI-62), concentrations of 1,4- and 1,2-dichlorobenzene decreased only slightly with depth in samples from a sediment core. However, similar to the pattern observed for PAH, dichlorobenzene concentrations in both sediment core intervals were 4-5 times greater than those observed in either of the surface (0-2 cm) sediment samples from Wheeler-Osgood Waterway. This difference suggests that any ongoing contaminant discharges are less than the historical discharges. These data would be consistent with a slow sedimentation rate in Wheeler-Osgood resulting in slow burial of contaminated sediments so that only a thin layer at the surface reflects a reduced contaminant discharge.

7.6.5.2 Loading Estimates--

The following discharges have been sampled for chlorinated benzenes, but the compounds have not been detected:

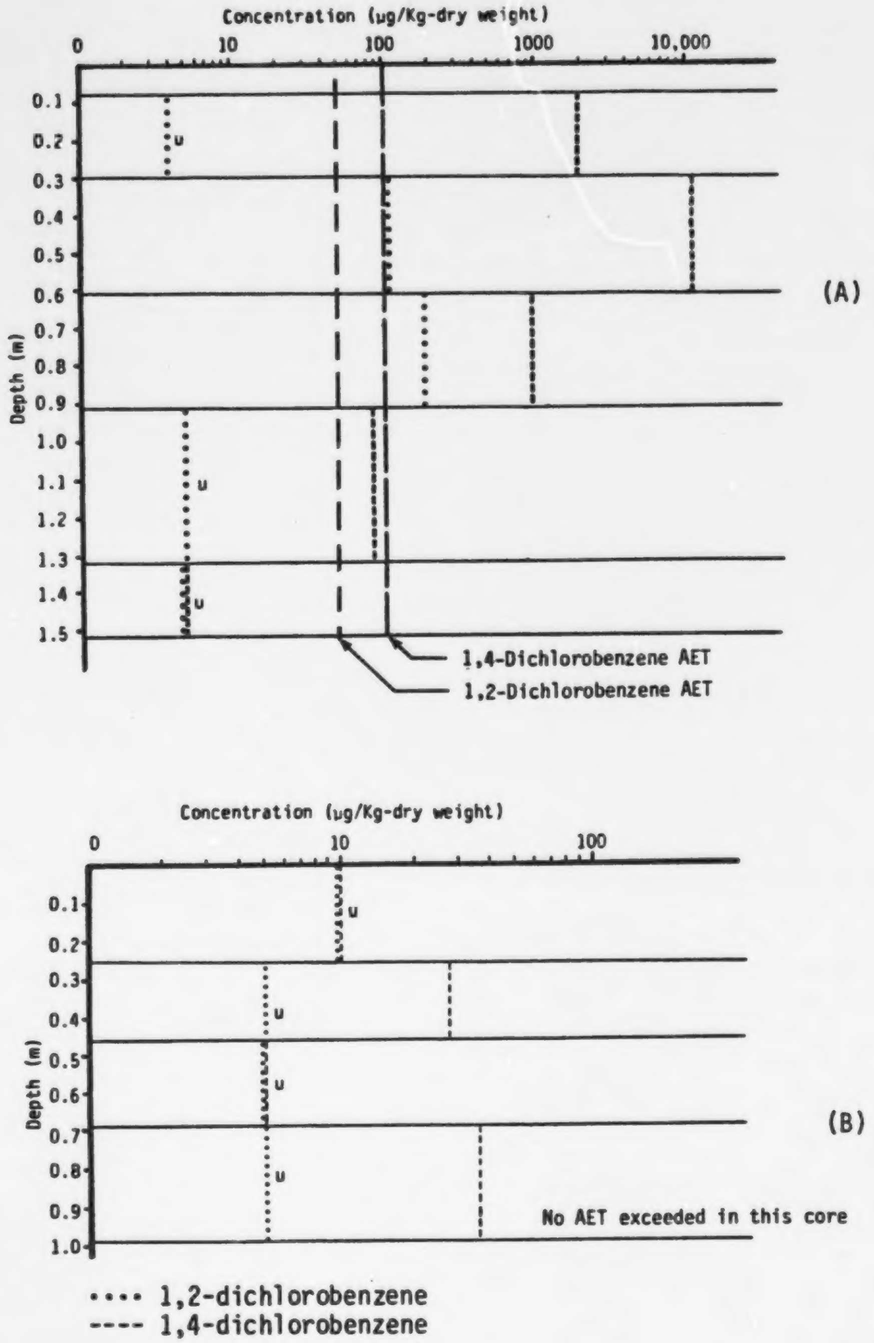


Figure 7.6.13 (A and B)

CONCENTRATIONS OF 1,2-DICHLOROBENZENE AND 1,4-DICHLOROBENZENE WITH DEPTH IN THE SEDIMENT COLUMN, (A) STATION CI-60, G05; (B) STATION CI-61, G01

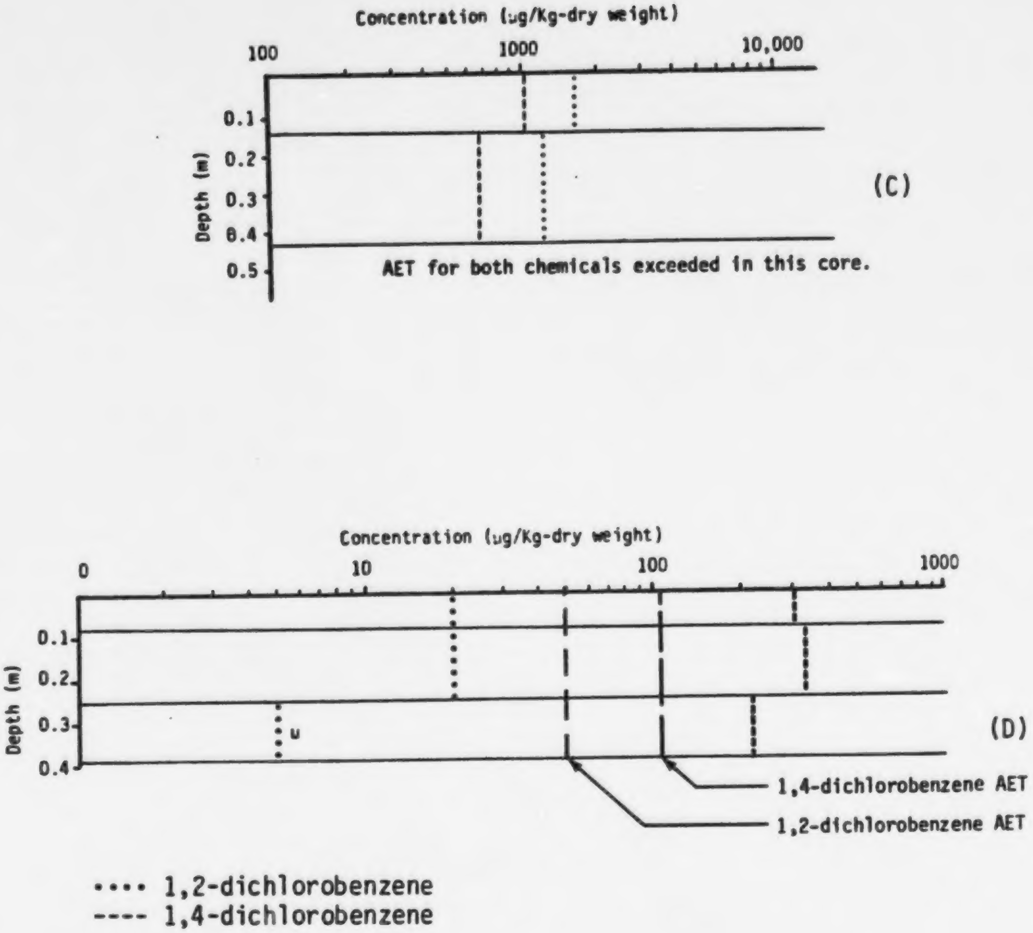


Figure 7.6.13 (C and D)

CONCENTRATIONS OF 1,2-DICHLOROBENZENE AND 1,4-DICHLOROBENZENE WITH DEPTH IN THE SEDIMENT COLUMN, (C) STATION CI-62, B02: (D) STATION CI-63, B01

Drain No.	No. of Sample Analyses	Detection Limit (ug/L)	Drain No.	No. of Sample Analyses	Detection Limit (ug/L)
CI-225	2	1.0	CI-248	2	1.0
CI-230	3	1-10	CI-703	1	1.0
CI-234	1	1.0	CN-237	7	0.5-10
CI-243	2	1.0	CS-237	3	1-10
CI-245	2	1.0	CW-254	4	1-10

Refer to Figure 7.6.2 for drain numbers and locations along the waterway.

7.6.5.3 Source Identification--

Because there are no documented dischargers of chlorinated benzenes to City Waterway, source identification efforts were based on probable use of the compounds. The chlorinated benzenes are used as fumigants and insecticides (Hawley 1981). 1,4-Dichlorobenzene is used as an air deodorant and toilet bowl deodorant. 1,2-Dichlorobenzene is used as a solvent for organic materials, a degreaser for hides and wool, and a solvent for oxides of nonferrous metals (Hawley 1981). Potential sources of dichlorinated benzenes in Wheeler-Osgood Waterway and City Waterway are discussed separately below.

Wheeler-Osgood Waterway (City Waterway Segment 2)--The known use of 1,2-dichlorobenzene as a degreaser for hides and the distinctive signature of chlorinated benzenes in Wheeler-Osgood Waterway suggest Carsten's Packing Company and Hygrade Foods as potential sources. Carsten's, a slaughtering house and meat packing plant, probably started operating in the 1920s. The company began leasing to Hygrade Foods around 1955. Hygrade eventually bought the company around 1960 (Brandt, C., personal communication). The meat packing plant had been a major discharger of untreated process wastes to the Wheeler-Osgood Waterway. The discharge of process wastes from Hygrade dropped significantly about 1970 after connection with the city of Tacoma's sanitary sewage system. However, as a result of unidentified cross-connections between the process effluent and the cooling water/storm runoff system, some discharge of process wastes to Wheeler-Osgood continued until at least the mid-1970s. Hygrade Foods is currently permitted to discharge only runoff noncontact cooling water to Wheeler-Osgood (Hygrade NPDES Permit).

The actual use and discharge of chlorinated benzenes by Carsten's Packing Company/Hygrade Foods has not been documented. A retired Hygrade employee (Brandt, C., personal communication) does not recall the use of chlorinated benzenes at Hygrade Food. In view of the known use of 1,2-dichlorobenzene as a degreaser for hides, this compound could be associated with this industry. According to D. Nelson (personal communication) of Frontier Leather Company, the tanning industry commonly used chlorinated benzenes as fugicides on hides prior to 1961. Since that time, salt has been more commonly used. No other known or potential sources of chlorinated benzenes to Wheeler-Osgood Waterway have been identified.

City Waterway (Segments 1 and 3)--The proportion of 1,4-dichlorobenzene relative to 1,2-dichlorobenzene was greater in sediments from City Waterway than in those from Wheeler-Osgood Waterway. This difference suggests a separate source in chlorinated benzenes in City Waterway.

Use of chlorinated benzenes by industries along the waterway could not be confirmed. Inquiries were made of plywood manufacturers (Puget Sound Plywood) and shipbuilders (Todd Shipyards) to determine whether this compound class is commonly used as a solvent in an industrial process, but they were unsuccessful.

Potential use of chlorinated benzenes by the Burlington Northern Railroad car washing yard on East 21st Street was investigated. According to Dames and Moore (1982), waste materials from this operation including solvents, chemicals, and oil, were disposed of on the ground at this site. However, a review of WDOE files indicated that the car washing yard is probably not a source of chlorinated benzene contamination to the City Waterway. According to the Burlington Northern's 1972 NPDES application, box cars containing only grain, lumber, canned goods, fertilizer, and a variety of food products are washed. The cars are cleaned with city water, and the effluent is discharged to the Puyallup River. Only the engine house area discharges to City Waterway. While it cannot be established with certainty that toxic chemicals were never handled at the car washing yard, it is assumed that the discharge always went to the Puyallup River and would not be associated with contamination in City Waterway. Discharge from the Burlington Northern engine house has historically been routed through an outfall at the head of City Waterway. If dichlorinated benzenes were used as solvents at this facility, they would have probably been released to City Waterway via this outfall. (It was not established during these investigations whether the engine house still exists; Burlington Northern's 1972 NPDES application indicated that it was scheduled for removal.)

The areas of elevated 1,4-dichlorobenzene concentrations (the head of City Waterway and 4,700 ft from the mouth) suggest possible input via the Nalley Valley, south Tacoma, and 15th Street drains. Alhough effluent sampling has failed to detect any dichlorinated benzenes from these discharges, these outfalls may be historical or intermittent sources of the compounds.

7.6.5.4 Summary and Recommendations--

Chlorinated benzenes are preliminary contaminants of concern in Segments 1, 2, and 3. The relative proportion of 1,2- and 1,4-dichlorobenzene in Segment 2 was different from that in Segment 1 and 5. This signature existed in both surficial sediments and deep cores, indicating separate sources of chlorinated benzenes in Wheeler-Osgood Waterway and the main portion of City Waterway.

The origin of chlorinated benzenes in Wheeler-Osgood Waterway is unknown. There is no evidence that 1,2-dichlorobenzene was used in the curing or tanning of hides at Carsten's Packing Company or Hygrade Foods. The presence of chlorinated benzenes in surficial sediments of Wheeler-Osgood Waterway suggests that contamination may be ongoing, but concentrations in 0-2 cm surface sediments were several times less than those observed in the two composited intervals (0-14 and 14-43 cm) of a core from the same area. A similar difference was noted for the main channel of City Waterway. The maximum 0-2 cm sediment concentration of 1,4-dichlorobenzene (290 ug/kg dry weight; Station CI-11) was less than 15 percent of the corresponding value for the 0-30 cm interval of the core collected in the same area. These data suggest that the dichlorobenzene load may have recently decreased in both City and Wheeler-Osgood Waterways.

Possible sources of chlorinated benzenes to the main portion of City Waterway include the Burlington Northern engine house and the drains of Nalley Valley, south Tacoma, and 15th Street. None of the sources can be confirmed.

The following recommendations may help focus further description of chlorinated benzene sources:

- Investigate Hygrade Foods and other properties with discharge via the Wheeler-Osgood drain to determine if there is an ongoing source of dichlorinated benzenes
- Investigate potential uses and sources of dichlorinated benzenes in the areas drained by the Nalley Valley, south Tacoma, and 15th Street drains.

7.6.6 4-Methylphenol

7.6.6.1 Spatial Distribution--

Surficial sediment concentrations of 4-methylphenol (Figure 7.6.14) ranged from 140 to 940 ug/kg dry weight (4,200 to 16,000 ug/kg TOC) in Segments 1 and 3 of City Waterway, and were 1,200 ug/kg dry weight (11,000 ug/kg TOC) in Segment 2 (Wheeler-Osgood Waterway). On a dry-weight basis, the area of greatest 4-methylphenol contamination was located between 3,700 and 4,700 ft from the mouth of the waterway (Stations CI-15, CI-17, CI-18). When normalized to TOC, 4-methylphenol concentrations in sediments from Stations CI-15, CI-17, and CI-18 remained high and those in sediments from the mouth of the waterway were also elevated. This pattern of contamination suggests a source between 3,700 and 4,700 ft from the waterway mouth and a second source at the mouth of City Waterway. The extent of contamination in Wheeler-Osgood Waterway is unclear given the variability of 4-methylphenol concentrations in the two samples taken [i.e., 270 ug/kg in January, 1984 (Station CI-01) and 1,200 ug/kg in March, 1984 (Station CI-16)]. The variability may have arisen from differences in analytical protocols, or from natural variability in the environment.

Throughout the waterway, concentrations of 4-methylphenol in sediment cores were essentially uniform within each core (Figure 7.6.15). No other compounds of concern in the waterway showed such homogeneity, presumably because 4-methylphenol is among the most soluble of the compounds examined

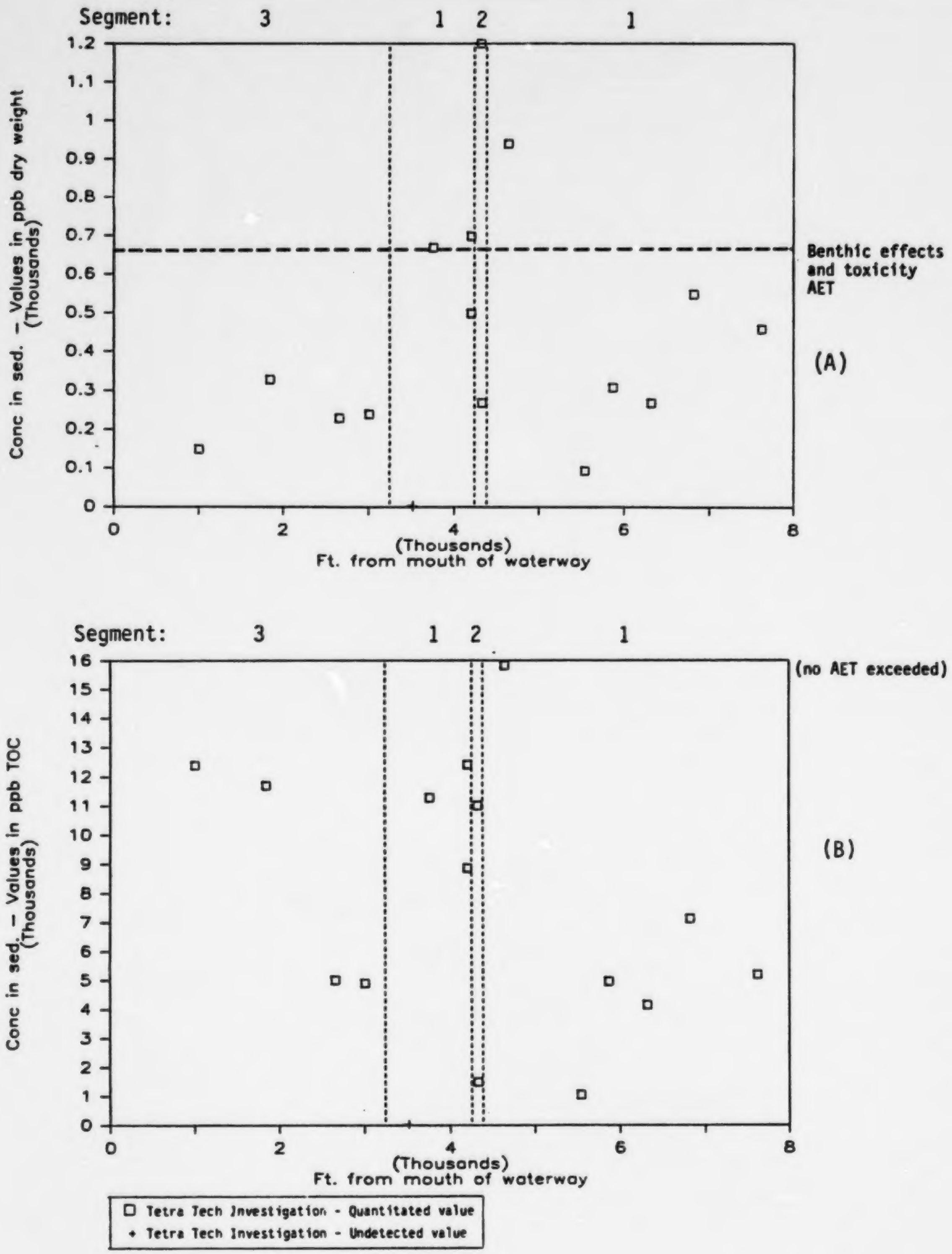


Figure 7.6.14

SURFICIAL SEDIMENT CONCENTRATIONS OF 4-METHYLPHENOL
IN CITY WATERWAY, (A) DRY WEIGHT BASIS, (B) NORMALIZED
TO TOTAL ORGANIC CARBON

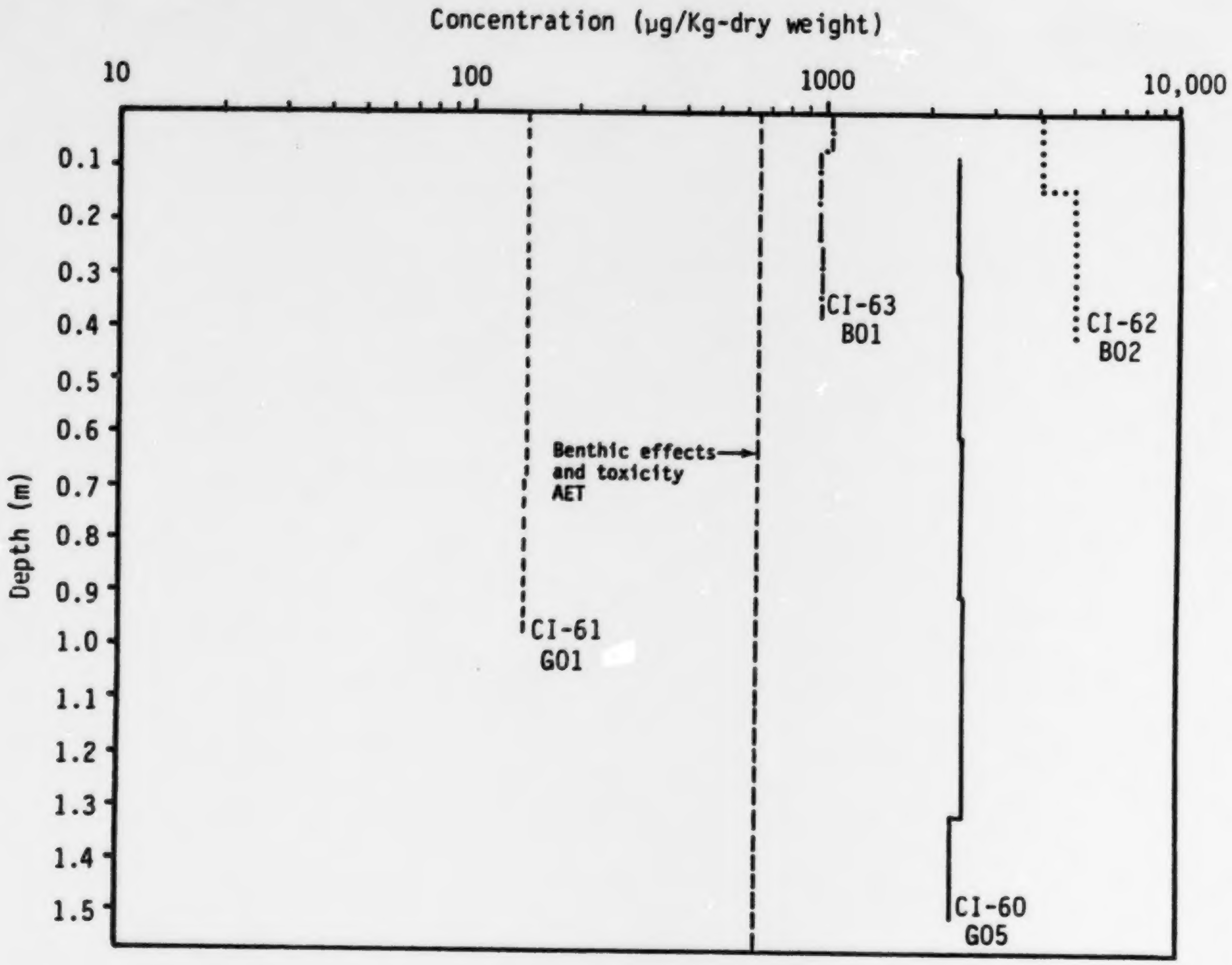


Figure 7.6.15

CONCENTRATION OF 4-METHYLPHENOL
WITH DEPTH IN THE SEDIMENT COLUMN
AT STATIONS IN CITY WATERWAY

and would therefore tend to migrate in the interstitial water. At every site in the nearshore/tideflats area where 4-methylphenol was detected, concentrations were nearly constant throughout the depth of all sediment cores. Therefore, its vertical distribution in the sediment cores provides little or no indication of the historical rate of contaminant input.

7.6.6.2 Loading Estimates--

The Nalley Valley drain (CN-237) is the only drain for which effluent has been analyzed for 4-methylphenol. In two analyses in 1984, 4-methylphenol was undetected at 1 ug/L (WDOE unpublished). There are no known permitted discharges of phenol to City Waterway.

7.6.6.3 Source Identification--

4-Methylphenol (p-cresol) is a coal tar derivative used in the production of phenolic resins, in ore flotation, and as a synthetic food flavoring. Although not a priority pollutant, it is on U.S. EPA's list of hazardous substances (U.S. EPA 1983c). Potential sources can be explored based on industrial types and known uses of this compound class by industries along the waterway.

Considerable wood debris was noted in sediments from Wheeler-Osgood Waterway. It was concluded in Section 7.4.4.2 that the anoxic degradation of wood chip debris in sediments is a possible source of alkylated phenols, including 4-methylphenol. The actual contribution (if any) to the total concentration of 4-methylphenol observed in Wheeler-Osgood Waterway sediments may only be speculated.

4-Methylphenol may enter City Waterway via discharge of wastewater containing phenolic resins used in plywood manufacturing. North Pacific Plywood, located at 1549 Dock Street (5,900 ft from waterway mouth), has manufactured plywood at this location since 1960 (Ruckelshaus 1985). The facility was originally built by the North Pacific Railroad to manufacture boilers for steam locomotives (Cook and Anderson 1983). According to Dames and Moore (1982), this facility deposited glue wastes on land in an unknown location, possibly on the property. The firm has a long history of spills of phenolic resins at the site, the most recent in December, 1977, when a hose from a tank truck ruptured and phenolic glue waste reached the waterway (Monahan 1978). Due to numerous spills in the vicinity, the ground beneath the glue tank had become saturated with phenolic resins, and the WDOE ordered removal of contaminated soil (Docket No. DE 78-162). WDOE was notified that contaminated soils had been removed on March 7, 1978. A storm drain in the immediate vicinity of the glue tank may have provided a route for spilled phenolic glues to reach the waterway since this drain was not sealed during resin handling operations until 1977 (Hall 1977).

While spills of phenolic resins to the ground and subsequent direct leaching to the waterway could be a source of 4-methylphenol to City Waterway, this route is not reflected in the spatial gradient of contamination of waterway sediments. Sediments at Station CI-14, located in the middle of the waterway off North Pacific Plywood, were less contaminated with 4-methylphenol than were many other City Waterway sediments.

The firm may have contributed to contamination of the waterway via the storm sewer system. Station CI-15, with the greatest 4-methylphenol contamination in City Waterway, is located near the outfall of the 15th Street drain (CI-230). This storm drain serves 1 mi^2 of Tacoma (21st Street to 8th Street, West to Grant Avenue, based on a map provided by the city of Tacoma Department of Public Works). The storm drain in the immediate vicinity of North Pacific Plywood's glue tank discharges through the 15th Street drain. It appears likely that North Pacific Plywood contributed phenols to City Waterway through this route.

Northern Pacific Plywood plant along City Waterway is being dismantled. Manufacturing operations have been moved to Graham.

Other potential sources of phenols from the wood products industry were investigated. Puget Sound Plywood is located at 230 East F Street, on the tip of the point of land separating City and Middle Waterways (see Figure 7.6.1). Phenolic glues have been spilled on the property (Dames and Moore 1982) and phenol-contaminated glue wastes have been disposed of on-site. Although contaminants originating from the site would probably reach Commencement Bay rather than City Waterway, this facility may have contributed to the 4-methylphenol contamination in sediments near the mouth of the waterway.

Harmon Cabinets, presently located at 1933 Dock Street (see Figure 7.6.1), has been in business since the late 1800s. Records do not indicate whether they have always been in business at this location on the waterway. The firm is served by the same storm drainage network noted above for North Pacific Plywood. It is unknown if phenolic resins are used in their furniture manufacturing operations or if these materials have been released to the environment. There is no evidence that Harmon Cabinets disposed of wastes on-site to the ground, directly to the waterway, or through spills (Dames and Moore 1982).

St. Regis Door Mill was a possible source of phenols to Wheeler-Osgood Waterway. St. Regis Door Mill had an NPDES permit (WA0003221, expired 1/31/78) to discharge to Wheeler-Osgood Waterway with limitations for oil and grease. According to the U.S. EPA staff evaluation report on the application (10/19/73), the oil and grease resulted from air compressor cooling water discharge. If the facility used glues and resins in door manufacturing, improper waste disposal may have contaminated the waterway. This facility is no longer operating. Its closing date is not known.

As a coal tar derivative, 4-methylphenol may be expected in wastes at the Tar Pits and Tacoma Spur (23rd and A Streets) coal gasification sites. A tar sample from the Tar Pits site (2202 East River Street) showed 80 mg/kg 4-methylphenol and 30 mg/kg 2-methylphenol (Kennedy-Jenks Engineers 1983). These substances were not included in groundwater analyses conducted at the Tar Pits site or at the Tacoma spur site (Hart-Crowser and Associates

1984). Given the concentration of 4-methylphenol in the tar at Tar Pits, the solubility of the compound, and the similarity of the materials buried at the Tar Pits and the Tacoma Spur site, it is reasonable to expect the compound to be found in the tar and groundwater at both sites.

Groundwater at the Tar Pits site appears to flow to the Puyallup River rather than to City Waterway (Kennedy-Jenks Engineers 1983). Groundwater from the Tacoma Spur site is expected to discharge to City Waterway south of 21st Street, within 700 ft of the head of the waterway (Hart-Crowser and Associates 1984). 4-Methylphenol concentrations in surficial sediments within this area showed some elevation when normalized to dry weight, but not when normalized to organic carbon. The Tacoma Spur site could be a significant source of 4-methylphenol to City Waterway. However, the sediment chemistry data available are inconclusive.

7.5.6.4 Summary and Recommendations--

Spatial distribution of 4-methylphenol in City Waterway indicates a source in Segment 1 between 3,700 and 4,700 ft from the mouth of the waterway and a possible second source near the mouth in Segment 3. Vertical 4-methylphenol concentrations were uniform in the sediment column.

The 15th Street drain (CI-230) is a possible source of 4-methylphenol in Segment 1. The highest levels of 4-methylphenol observed in City Waterway sediments were observed in samples taken in the middle of the waterway near this outfall. North Pacific Plywood, a plywood manufacturer and heavy user of phenolic resins, was located (until 1983) within the drainage area served by this storm drain. The firm had a history of spills at the site. Spilled materials could have been transported to the waterway via the storm drain located in the vicinity of the glue tanks. The plant has recently closed and contamination from this source is presumed to be historical. It is unknown whether there are other historical or ongoing sources of 4-methylphenol within the drainage area by the 15th Street drain. Discharges and spills from Puget Sound Plywood at the mouth of the waterway may be contributing to contamination of sediments at the mouth of the waterway.

The Tacoma Spur coal gasification site is probably a historical and ongoing source of 4-methylphenol to City Waterway. At the present time, groundwater from the site may contribute 4-methylphenol to City Waterway, although the sediment quality data available provide only limited evidence of its impact. The Tar Pits site is a potential source of 4-methylphenol to the Wheeler-Osgood and City Waterways via groundwater. Degradation of buried wood chip debris may also contribute to the 4-methylphenol concentrations observed.

The following recommendations may help focus further description of 4-methylphenol sources:

- Investigate potential sources of 4-methylphenol within the drainage area served by the 15th Street drain

- Investigate the Tacoma Spur coal gasification site as a source of 4-methylphenol to City Waterway via groundwater, since there are no data available to indicate the extent or magnitude of 4-methylphenol contamination on the property

- Investigate the Tar Pits site a source of 4-methylphenol to Wheeler-Osgood and City Waterways via groundwater.

- Investigate the production of 4-methylphenol in decaying wood debris as a potential source to Wheeler-Osgood Waterway

4-Methylphenol has a lower affinity for sediments and associated organic material than do many of the other contaminants of concern in the nearshore/tideflats area. Source control efforts should be particularly effective because the compound would not be expected to persist in the sediments if sources could be eliminated. This factor also suggests that removal of contaminated sediments would not be an appropriate remedial action, unless possible in situ degradation of wastes in the sediments produced sufficient 4-methylphenol to be a problem over time.

7.6.7 Polychlorinated Biphenyls

7.6.7.1 Spatial Distribution--

The distribution of polychlorinated biphenyls (PCBs) in the surficial sediments of City Waterway, based on the Tetra Tech surveys and all historical data, is illustrated in Figure 7.6.16. PCB concentrations in surficial sediments in City Waterway typically were below 200 ug/kg dry weight, with the exception of data from historical surveys near the mouth of the waterway. The two data points with elevated PCB concentration at about 2,300 ft from the waterway mouth were those of Malins et al. (1980). In general, the PCB distribution throughout the waterway was patchy, with no distinct pattern.

Two sediment core samples were available in Segment 1. In sample CI-63, approximately 4,700 ft from the waterway mouth, PCBs were undetected at 100-110 ug/kg throughout the core. In core CI-60 at the head of the waterway, PCB concentrations increased with depth in the sediment and then decreased in the lowest horizon (Figure 7.6.17). The elevation in concentration at depth in sediment from Segment 1 indicates that historical input is greater than present input. In the deep core in the lower waterway (CI-61), PCBs were undetected at 70-90 ug/kg throughout the core.

7.6.7.2 Loading Estimates--

PCBs have never been detected in storm drain discharges to City Waterway. The following outfall discharges have been analyzed for PCBs:

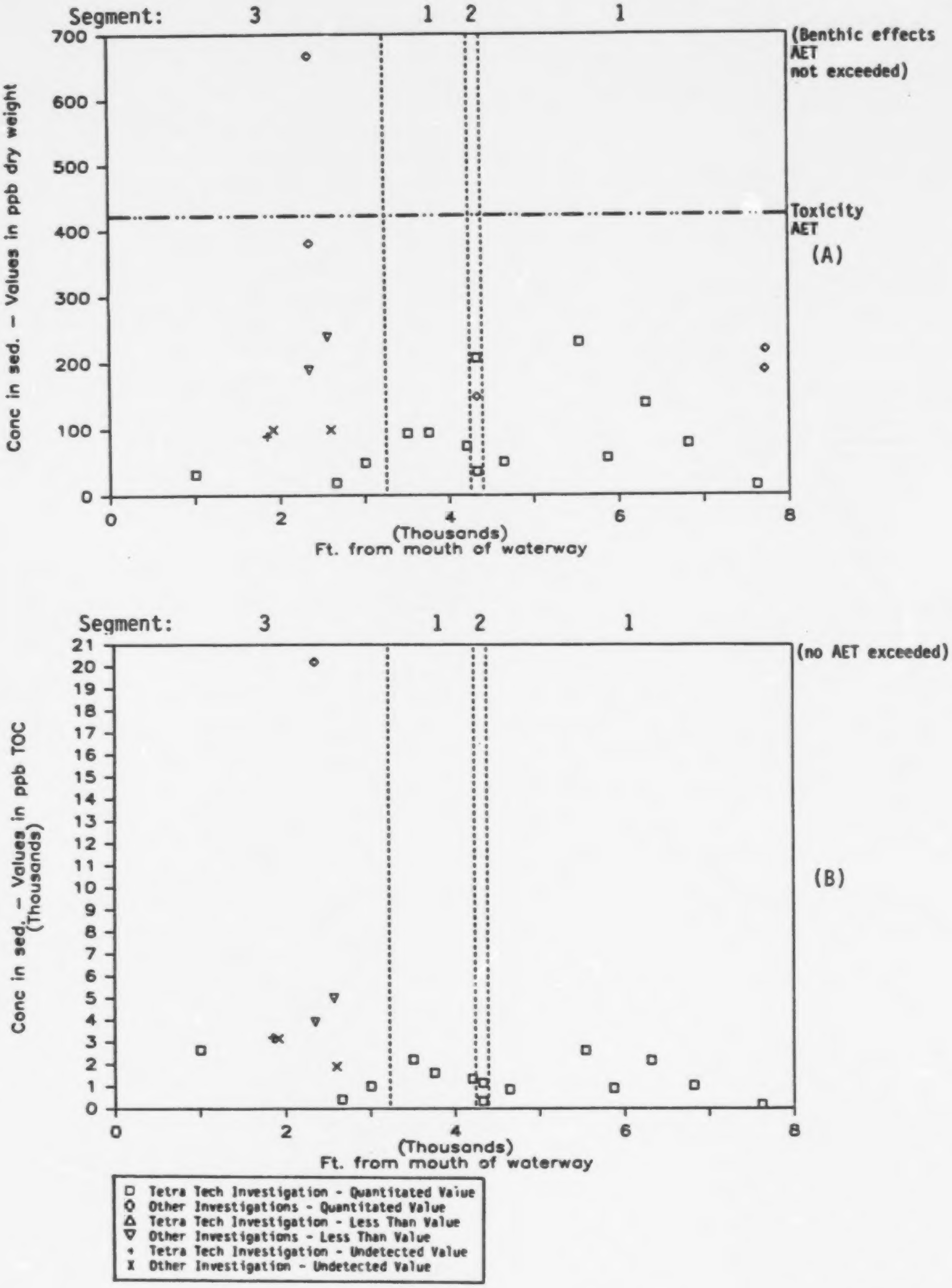


Figure 7.6.16

SURFICIAL SEDIMENT CONCENTRATIONS OF PCBs
IN CITY WATERWAY, (A) DRY WEIGHT BASIS, (B) NORMALIZED
TO TOTAL ORGANIC CARBON

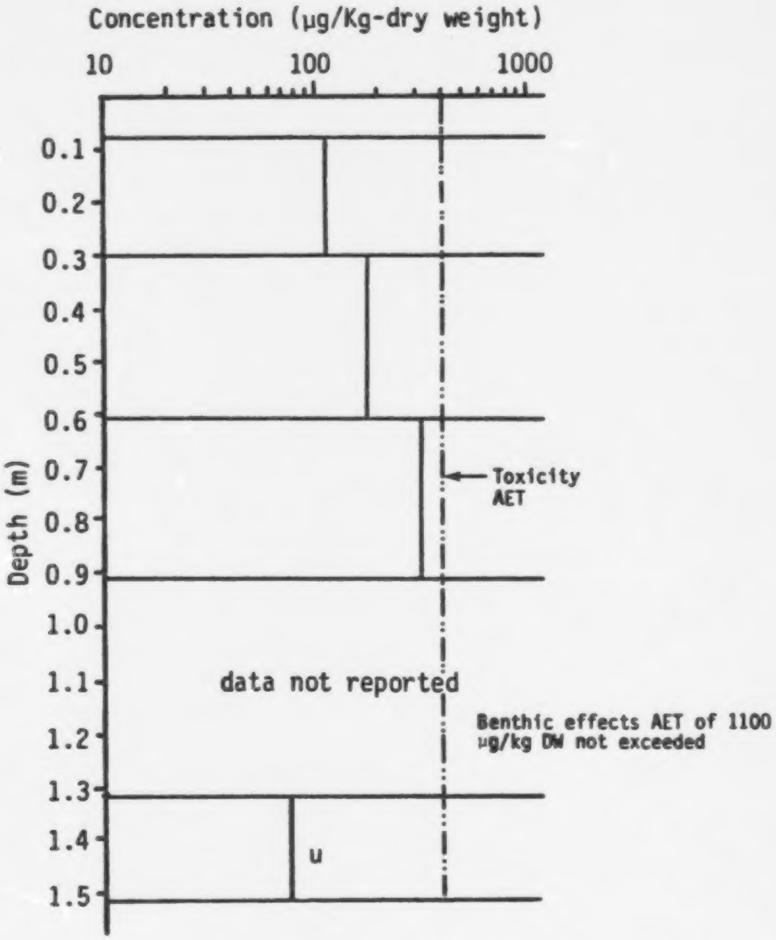


Figure 7.6.17

CONCENTRATION OF PCBs WITH DEPTH IN THE SEDIMENT AT STATION CI-60, G05 NEAR THE HEAD OF CITY WATERWAY

u = undetected at concentration shown

Drain No.	Sample Analyses	Detection Limit (ug/L)	Drain No.	Sample Analyses	Detection Limit (ug/L)
CI-225	1	0.5-2.0	CI-248	1	0.5-2.0
CI-230	2	0.1-2.0	CI-703	1	0.5-2.0
CI-234	1	0.5-2.0	CN-237	7	0.05-2.0
CI-243	1	0.5-2.0	CS-237	2	0.5-2.0
CI-245	1	0.5-2.0	CW-254	3	0.5-2.0

Although these measurements cannot be considered complete, they indicate that PCBs are not presently discharged via storm drains in measurable quantities.

7.6.7.3 Source Identification--

The absence of clear spatial gradients in the surficial sediment data and the lack of discharge data related to PCBs complicates source identification. PCBs are used in heat-exchange and insulating fluids in transformers, paints, and hydraulic oils (Young et al. 1979). Their manufacture was banned in 1976. Based on their use in transformers, PCBs may be present on properties occupied by industries with a high electrical demand. The industries surrounding City Waterway in the area of greatest PCB contamination include a furniture manufacturer, a plywood manufacturer (now closed), a roofing contractor, a shipbuilder, a plywood distributor, a grocery warehouse, and a railroad yard. None of these facilities is known to handle large amounts of PCB-contaminated material, nor has there been any known release of PCBs from these firms.

There is no known release of PCBs through drains entering the waterway, and there is no gradient of sediment contamination to implicate any of these drains as a source.

Spills of PCBs to City Waterway have not been reported in the last 7 yr (WDOE Environmental Complaint files 1979-1985).

7.6.7.4 Summary and Recommendations--

PCB levels in surficial sediments of City Waterway were variable with no apparent gradients. Historical measurements at about 2,500 ft from the Waterway mouth indicated concentrations ranging from 200 to 700 ug/kg dry weight. No defined hot spots were identified in the recent data. Available data indicate that PCBs occur throughout the waterway at variable levels. It was not possible to identify the source of this contamination. A reconnaissance survey may be helpful in identifying potential PCB sources.

7.6.8 Copper and Zinc

7.6.8.1 Spatial Distribution--

Surficial sediment concentrations (dry weight) of copper and zinc in City Waterway showed similar spatial trends. The spatial gradients of contamination along the length of the waterway are shown in Figure 7.6.18, using data from the Tetra Tech 1984 survey and all available historical sediment data. Concentrations generally decreased from the head of the waterway to the mouth for both copper and zinc. Concentrations in sediments from several stations at 4,500-5,000 ft from the waterway mouth were elevated relative to those elsewhere in the waterway, up to a maximum of 2,100 mg/kg dry weight for each metal. These stations were located along the eastern shore of the waterway in the vicinity of Martinac Shipbuilding and were sampled by Norton and Johnson (1984). Concentrations of copper and zinc were also elevated in Wheeler-Osgood Waterway, but to a lesser extent than along Martinac Shipbuilding. Normalization of these data to percent fine-grained material did not indicate other trends.

Sediment core data from a station at the head of the waterway (CI-60) are illustrated in Figure 7.6.19. Copper concentrations showed a slight increase (i.e., factor of 1.5) with depth in the sediment down to 1.3 m. The copper concentrations in surface sediments (0-2 cm) from this area were similar to that in the top 30 cm interval of the core. Zinc concentrations were also similar between the 0-2 cm surface sediment sample and the 0-30 cm sediment core interval, but increased fivefold with depth down to 1.3 m. Below 1.3 m, the concentrations of both copper and zinc decreased abruptly. From these data it appears that after an initial buildup, the input of copper has decreased only slightly over time while that of zinc has decreased significantly.

The spatial pattern of metals contamination suggests that a major source of metals is located at the head of City Waterway. The data of Norton and Johnson (1984) also indicate a source along the eastern shore of the waterway, approximately 4,500-5,000 ft from the mouth. A source is also possible in Wheeler-Osgood Waterway, although data are not conclusive.

7.6.8.2 Loading Estimates--

There are currently no NPDES-permitted discharges of copper or zinc to City Waterway. Prior to 1978, American Plating (at one time known as Puget Sound Plating) had an NPDES permit to discharge process effluent directly to the waterway, although the firm currently discharges process wastewaters to the city sanitary sewer system.

Storm drain discharges have been sampled on a number of occasions over the last 4 yr to determine metal loadings. Results are summarized in Tables 7.6.6 and 7.6.7. Copper was found in five drains. The largest input (2.0 lb/day) was found in the south Tacoma drain (CS-237). The Nalley Valley drain (CN-237, 0.84 lb/day) and the 15th Street drain (CI-230, 0.3 lb/day) were also major contributors of copper. Zinc was found in 10 drains.

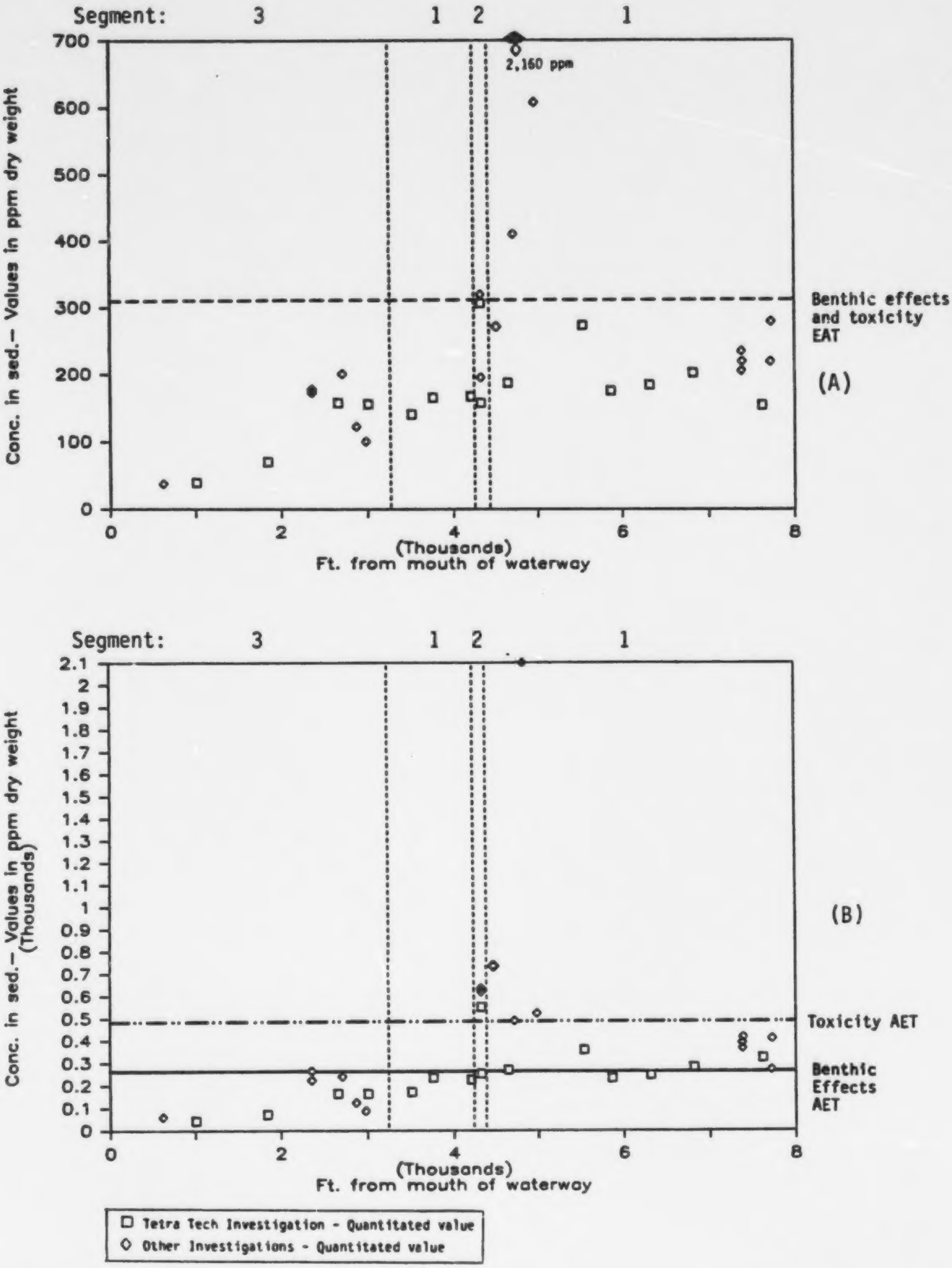


Figure 7.6.18

SURFICIAL SEDIMENT CONCENTRATIONS OF
(A) COPPER, AND (B) ZINC IN CITY WATERWAY

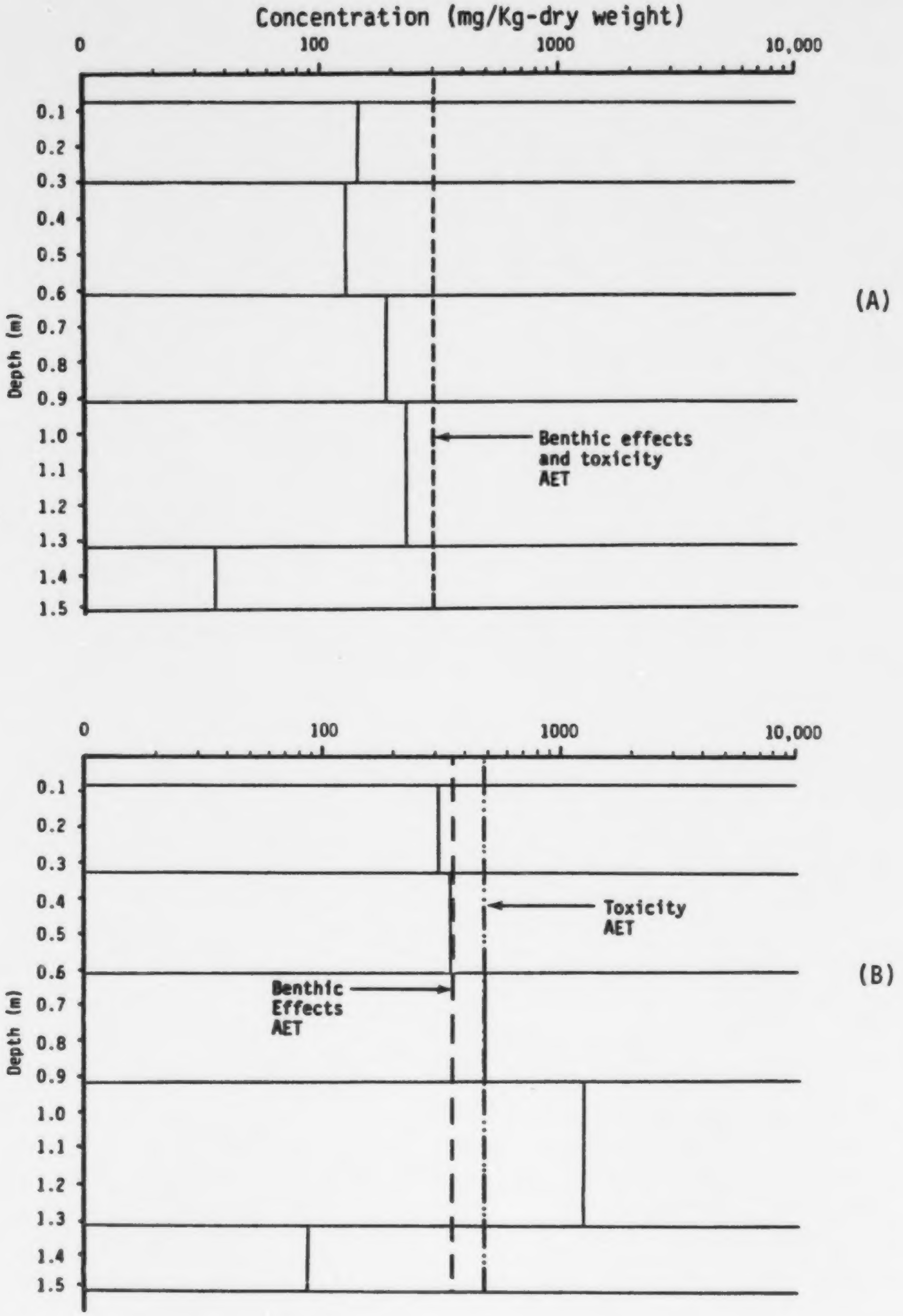


Figure 7.6.19

CONCENTRATION OF (A) COPPER, AND (B) ZINC WITH DEPTH OF SEDIMENT AT STATION CI-60, G05 NEAR THE HEAD OF CITY WATERWAY

Table 7.6.6

COPPER: SUMMARY OF LOADINGS FROM DISCHARGES TO THE CITY WATERWAY

Drain #	Drain Name	Flow (MGD) (Avg. and Range) (# of Observations)	Period of Observations for Contaminant Concentrations	Concentration (ug/l) (Avg. and Range) (# of Observations)	Loading (lbs/day) (Avg. and Range)
CI-230	15th Street storm drain, 48" concrete pipe	0.17 (0.14-0.22) (n=3)	4/28/82-11/21/83	210 (7-420) (n=2)	0.30 (0.0099-0.60)
CI-234	24" wood box outfall at South 21st Street	0.034 (0.03-0.037) (n=2)	11/21/83	34 --- (n=1)	0.0096 ---
CI-248	18" concrete pipe, 850 ft south of 15th Street	0.020 (0.01-0.03) (n=2)	11/21/83	10 --- (n=1)	0.0017 ---
CN-237	Nalley Valley Drain	3.6 (1.2-10.66) (n=8)	7/28/81 - 10/26/83	28 (6-60) (n=5)	0.84 (0.18-1.8)
CS-237	South Tacoma Drain	4.8 (2.58-10.98) (n=4)	2/16/82	50 --- (n=1)	2.0 ---
CW-254	30" steel storm drain east end of Wheeler-Osgood Waterway	0.29 (0.13-0.63) (n=4)	7/28/81-11/7/83	24 (10-40) (n=3)	0.058 (0.024-0.097)

NOTE: Copper has been analyzed for but not detected in the following drains CI-225(1), CI-243(1), CI-245(1), CI-703(1), CS-237(2) (the number in parentheses represents number of analyses). Detection limit for all samples was 1 ug/l.

Table 7.6.7

ZINC: SUMMARY OF LOADINGS FROM DISCHARGES TO THE CITY WATERWAY

Drain #	Drain Name	Flow (MGD) (Avg and Range) (# of Observations)	Period of Observations for Contaminant Concentrations	Concentration (μg/l) (Avg and Range) (# of Observations)	Loading (lbs/day) (Avg and Range)
CI-255	36" Concrete Stormdrain under 11th St. Bridge	0.051 (0.032-0.07) (n=2)	9/7/83-11/21/83	11 (9-12) (n=2)	0.0046 (0.0038-0.0051)
CI-230	15th St. Stormdrain, 48" Concrete Pipe	0.17 (0.14-0.22) (n=3)	4/28/82-11/21/83	170 (38-365) (n=3)	0.24 (0.54-0.52)
CI-234	24" Wood Box Outfall at S. 21st Street	0.034 (0.03-0.037) (n=2)	9/7/83-11/21/83	20 (15-25) (n=2)	0.0057 (0.0043-0.0071)
CI-243	21" Steel Pipe Stormdrain from RR Yard	0.37 (0.21-0.52) (n=2)	9/7/83-11/21/83	35 (16-54) (n=2)	0.11 (0.049-0.17)
CI-245	18" Concrete Pipe Stormdrain from RR Yard	0.070 (0.05-0.09) (n=2)	9/7/83-11/21/83	30 (10-50) (n=2)	0.018 (0.0058-0.029)
CI-248	18" Concrete Pipe, 850 ft S of 15th Street	0.020 (0.01-0.03) (n=2)	9/7/83-11/21/83	33 (30-35) (n=2)	0.0055 (0.0050-0.0058)
CI-703	Concrete Pipe Drain at Harmon's Furniture	0.075 (0.06-0.09) (n=2)	9/7/83-11/21/83	9.0 --- (n=2)	0.0056 ---
CN-237	Nalley Valley Drain	3.6 (1.2-10.66) (n=8)	7/28/81-4/17/84	47 (2-180) (n=8)	1.4 (0.15-5.4)
CS-237	South Tacoma Drain	4.8 (2.58-10.98) (n=4)	9/7/83-11/21/83	29 (2-80) (n=3)	1.2 (0.080-3.2)
CW-254	30" Steel Stormdrain E End of Wheeler-Osgood Waterway	0.29 (0.13-0.63) (n=4)	7/28/81-11/7/83	79 (42-140) (n=4)	0.19 (0.10-0.34)

The largest loading (1.4 lb/day) was calculated for the Nalley Valley drain (CN-237). The south Tacoma and the 15th Street drains contributed 1.2 and 0.24 lb/day of zinc, respectively. There was also a substantial discharge of zinc (0.19 lb/day) from the storm drain at the head ofthe Wheeler-Osgood Waterway (CW-254). Care should be taken in interpreting the loading data in Tables 7.6.6 and 7.6.7 due to the small sample sizes and the poor characterization of contaminant discharges during storm events. Data from the Nalley Valley drain (CN-237) were better than other data, but those for a complete storm event were not available.

Most of the information pertaining to the concentration of metals in discharges to City Waterway has been collected since 1981. However, until 1979, untreated combined storm and sanitary sewers discharged directly to City Waterway, carrying domestic and industrial wastes (see Section 7.6.3). Therefore, it seems likely that historical metals loading from discharges to City Waterway may have been greater than indicated by the recent data available.

7.6.8.3 Source Identification--

Storm drains, particularly the Nalley Valley/south Tacoma drains, appear to be the major sources of metals to City Waterway based on the sediment chemistry and loading data. Martinac Shipbuilding and American Plating are also potential sources. These three sources are addressed individually below.

Storm Drains--Storm drains accounted for a metals loading of 3.2 lb/day copper and 3.2 lb/day zinc to City Waterway. Most of the loading (88 and 81 percent copper and zinc, respectively) was attributed to the south Tacoma and Nalley Valley drains at the head of the waterway. These two drains serve portions of the I-5 corridor, the Nalley Valley, and south Tacoma to South 80th Street along Pacific Avenue (Figure 7.6.20). Although effluent from these drains is principally runoff, there may still be some unidentified industrial discharges to these sewer systems. The magnitude of potential unpermitted industrial input cannot be established.

Urban runoff probably accounts for much of the discharge of copper and zinc to the head of City Waterway. Wigington et al. (1983) indicate that zinc particulates result from tire wear (zinc is used as a binding agent in automobile tires). The metal is also found in motor oil. Copper is found in brake linings (Wigington et al. 1983) and antifreeze (up to 76 mg/L). Antifreeze is commonly dumped down storm drains when local residents change antifreeze in their radiators or perform other auto maintenance tasks. Particulate copper from brake lining wear would be washed into the storm sewer during storms and street sweeping operations. Corrosion of copper- and zinc-galvanized plumbing probably also adds metals to urban runoff (Cle et al. 1984). The primary source of zinc to the environment is the weathering and abrasion of galvanized iron and steel (Galvin and Moore 1982). In western Washington, where the water is naturally soft, this corrosion could represent a substantial source. With the separation of storm and sanitary sewers, discharges from this source should be reduced,

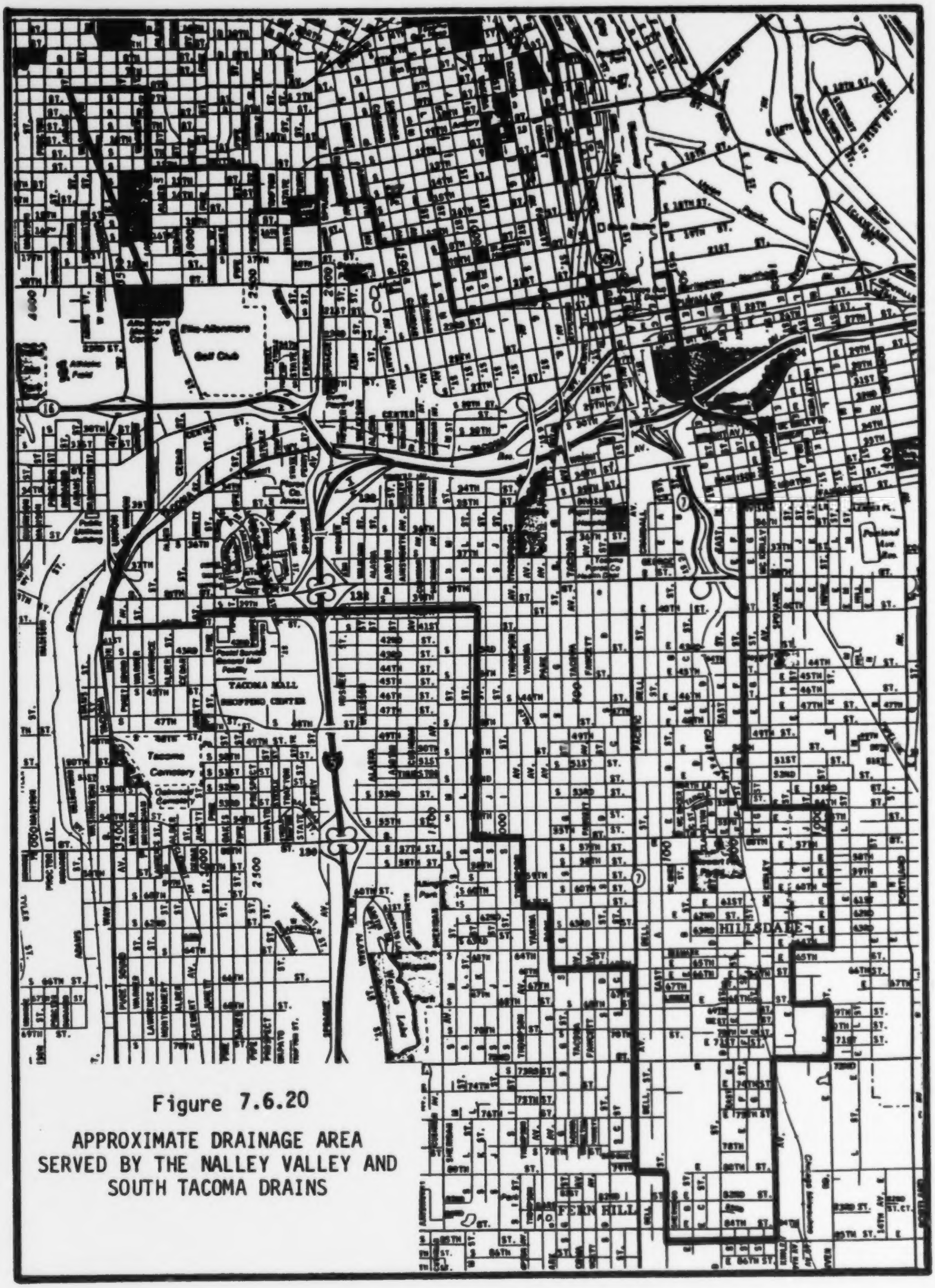


Figure 7.6.20

APPROXIMATE DRAINAGE AREA SERVED BY THE NALLEY VALLEY AND SOUTH TACOMA DRAINS although there may still be some contribution from unidentified process discharge connections or from noncontact cooling water discharges to the storm sewer system.

The range of values obtained during sampling of the City Waterway drains indicate that time of sampling and type of sample are important in obtaining representative contaminant loading data. Only 1-6 percent of copper and 0.8-8.0 percent of zinc are soluble (Wigington et al. 1983); both contaminants will be transported primarily in the particulate phase. It is possible to measure high concentrations during the first flushing of the sewer during a storm, but, as flows increase, loading of contaminants may increase even as concentrations begin to decrease (Helsel et al. 1979). For this reason, the February 16, 1982 storm sampling of the Nalley Valley and south Tacoma drains showed 74 and 320 mg/L TSS with correspondingly high flows and metals concentrations, and therefore high loadings of copper and zinc (Norton and Johnson 1984). In contrast, samples of effluent from these same drains collected November 21-22, 1984 following 6 days of rain had <1 mg/L TSS in both drains, concentrations of zinc were low, and copper was undetected. Despite the uncertainties in the loading data, the Nalley Valley and south Tacoma drains are the major sources of copper and zinc to City Waterway.

Martinac Shipbuilding--The highest concentrations of metals reported in City Waterway sediments were found along the waterfront adjacent to Martinac Shipbuilding (Norton and Johnson 1984). Located just north of 15th Street, Martinac Shipbuilding has been building and repairing ships at this site since 1924. Both sandblasting grit and antifouling paints may be sources of zinc- and copper-contaminated materials to the waterway. A coarse-grained black sand with high metal concentration levels was found just offshore of the Martinac property (Norton and Johnson 1984). Subsequent investigation revealed that a sandblasting material known as "Tuf-Kut" is used at this facility. Information supplied by the manufacturer indicates that this blasting sand contains 1,300-5,000 mg/kg copper and 75 mg/kg zinc. Concentrations of these contaminants in nearby waterway sediments were 2,160 mg/kg copper and 2,100 mg/kg zinc (Norton and Johnson 1984). It is also possible, although not confirmed, that Martinac Shipbuilding used granulated ASARCO slag as sandblasting material, as had been common in the Tacoma area (Norton and Johnson 1984). ASARCO slag "typically" has 5,000 ppm copper and 18,000 ppm zinc (ASARCO 1971).

Antifouling paints use any of several trace metals as toxic agents. Copper is a common constituent in these paints. At a ship building/repairing facility such as Martinac, antifouling paints would be removed from boat hulls during sandblasting operations. These paints could represent a significant source of copper and other metals (e.g., cadmium and tin) if permitted to enter the waterway.

The contribution of historical and ongoing practices at Martinac to the metals contamination in the sediments is unknown. Sandblasting activities and the use of antifouling paints are likely sources of contamination.

American Plating (Puget Sound Plating)--American Plating is located at the head of City Waterway, where sediments are contaminated with metals. Metals concentration in nearshore sediments in the vicinity of American Plating were similar to those in offshore sediments near the head of the waterway. Although American Plating may be contributing to the overall contamination, it does not appear to be a major contributor. This electroplater has been located at the upper end of City Waterway since 1975. Other electroplaters (Puget Sound Plating and Seymour Electroplating) have occupied the same property since 1955. Prior to 1978, the company was permitted to discharge process wastes to City Waterway. WDOE files indicate numerous permit violations. Subsequent to 1978, American Plating was connected to the Tacoma Sewer Utility lines, and no longer had a permitted discharge to the waterway. Plating wastes have been spilled at least 10 times since 1979, as documented in WDOE files. There have been two recent spills of zinc-contaminated wastes. On October 6, 1981, an unknown volume of waste containing 4 mg/L zinc was spilled on the property (WDOE files). On December 6, 1984, the company reported a spill of unknown volume of zinc-contaminated effluent to the waterway. No copper waste spills have been documented on American Plating property, although copper plating is performed at the facility.

7.6.8.4 Summary and Recommendations--

Copper and zinc showed similar gradients of contamination in City Waterway sediments, decreasing in concentration from the head to the mouth of the waterway. Concentrations in Wheeler-Osgood Waterway were also elevated. Contamination gradients suggest a source near the head, a source about 5,000 ft from the waterway mouth, and a possible source in Wheeler-Osgood. Core data indicate that historical sediment accumulations of at least zinc were greater than current accumulations.

The major current and historical sources of copper and zinc to the waterway are the Nalley Valley and south Tacoma drains at the head of the waterway. These two drains contribute over 80 percent of the quantified copper and zinc loading to City Waterway. The relative inputs to the storm drains from street runoff versus potential unpermitted industrial discharges cannot be estimated.

The 15th Street and Wheeler-Osgood drains represent ongoing sources of metals to City Waterway. The 15th Street drain contributes 10 percent of the quantified copper loading to the waterway and 8 percent of the zinc loading. The Wheeler-Osgood drain contributes 2 percent of quantified copper loading and 6 percent of the quantified zinc loading.

Martinac Shipbuilding is probably a significant historical and ongoing localized source to the waterway. Loading cannot be estimated from this source, and the total amount of material discharged is unknown.

American Plating has a history of chronic spillage of plating wastes to the upper waterway. However, available data indicate that American Plating is not presently a major source of copper and zinc to the waterway.

A drainage basin study should be conducted to determine the major sources of copper and zinc to the storm drains entering City Waterway. This should include an attempt to identify unpermitted industrial or municipal connections. Even if industrial sources can be identified and eliminated, urban runoff is expected to remain a major source of both copper and zinc. Reducing the metals input from runoff will require minimizing the amount of particulate material discharged via the storm drains. Alternative techniques to accomplish this goal are discussed in Section 7.6.9.5. If loadings of copper and zinc from the Nalley Valley and south Tacoma drains can be significantly reduced, a measureable improvement in sediment quality in City Waterway can be expected over time. It is not possible to estimate the rate of improvement because of the lack of data on sediment transport and deposition within the waterway.

Continued monitoring and enforcement action at American Plating are recommended. Activities at Martinac Shipbuilding should be investigated to determine their contribution of contaminants to the waterway. Sources of zinc and copper to Wheeler-Osgood Waterway should be investigated.

7.6.9 Lead

7.6.9.1 Spatial Distribution--

Lead concentrations (dry weight) in City Waterway surficial sediments decreased steadily from the head to the mouth of the waterway. This is apparent in Figure 7.6.21, which presents data from the Tetra Tech 1984 survey and from all available historical studies. The gradient of contamination evident in this figure indicates that the major source of lead is located at the head of the waterway and that a possible source exists in Wheeler-Osgood Waterway. No other major sources along the length of the waterway are apparent. Normalization of lead concentrations to percent fine-grained material did not reveal other trends.

The vertical contamination gradient in sediments from Station CI-60 at the head of the waterway (Figure 7.6.22) indicates that lead input to City Waterway sediments has steadily increased. The Station CI-60 core showed a concentration of 48 mg/kg in the lowest horizon (1.3-1.52 m). Above that, concentrations ranged from about 470 mg/kg in the 0.9 to 1.3-m horizon to 1,040 mg/kg in the 0.1 to 0.3-m horizon. Elsewhere in the waterway concentrations were more uniform throughout the core.

7.6.9.2 Loading Estimates--

Lead loading data are available from 10 storm drains discharging to City Waterway (Table 7.6.8). In two other drains (one sample each), lead was not detected at 1 ug/L. These data should be evaluated and used with care, since most values are based on only two or three sampling events. The exception is the Nalley Valley drain (CN-237) for which there were seven sampling events. The Nalley Valley drain (CN-237) and south Tacoma drain (CS-237) contributed 87 percent of the quantified lead input to the

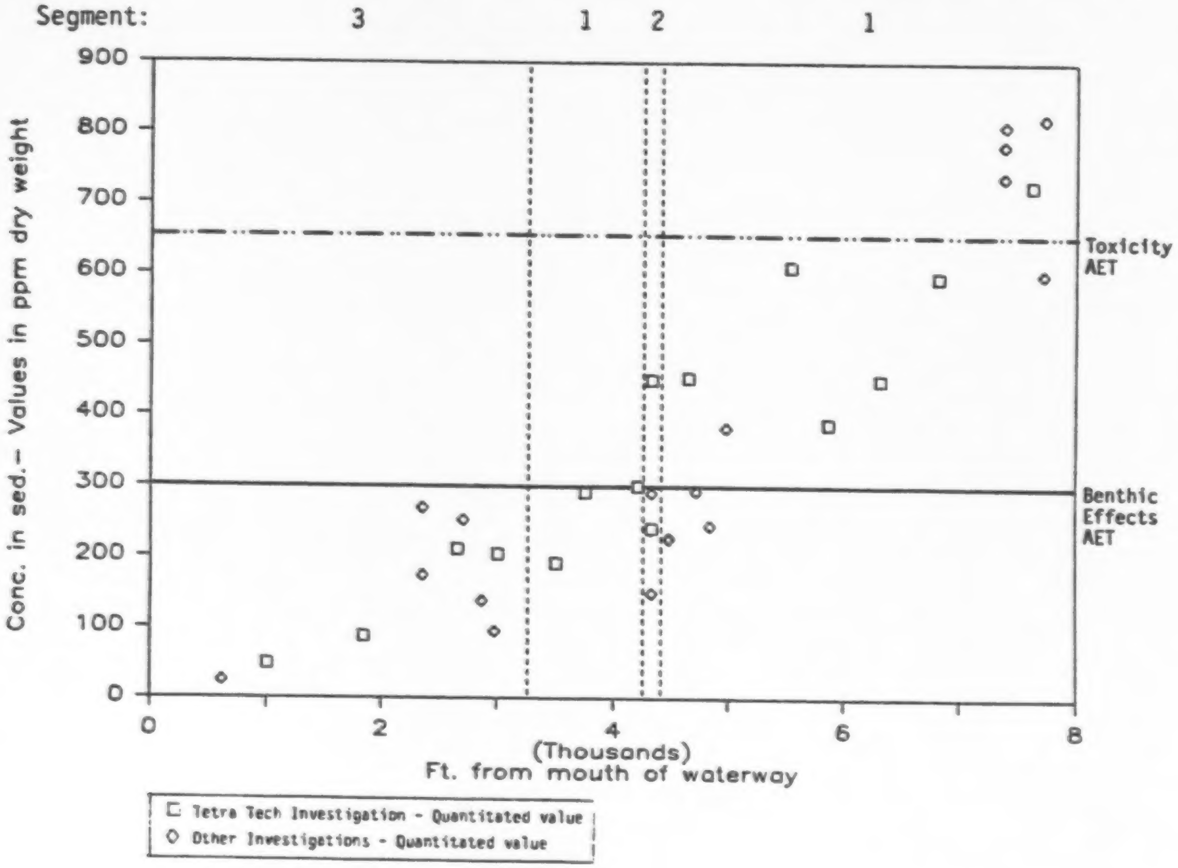


Figure 7.6.21

SURFICIAL SEDIMENT CONCENTRATIONS OF
LEAD IN CITY WATERWAY
Concentrations on a dry weight basis

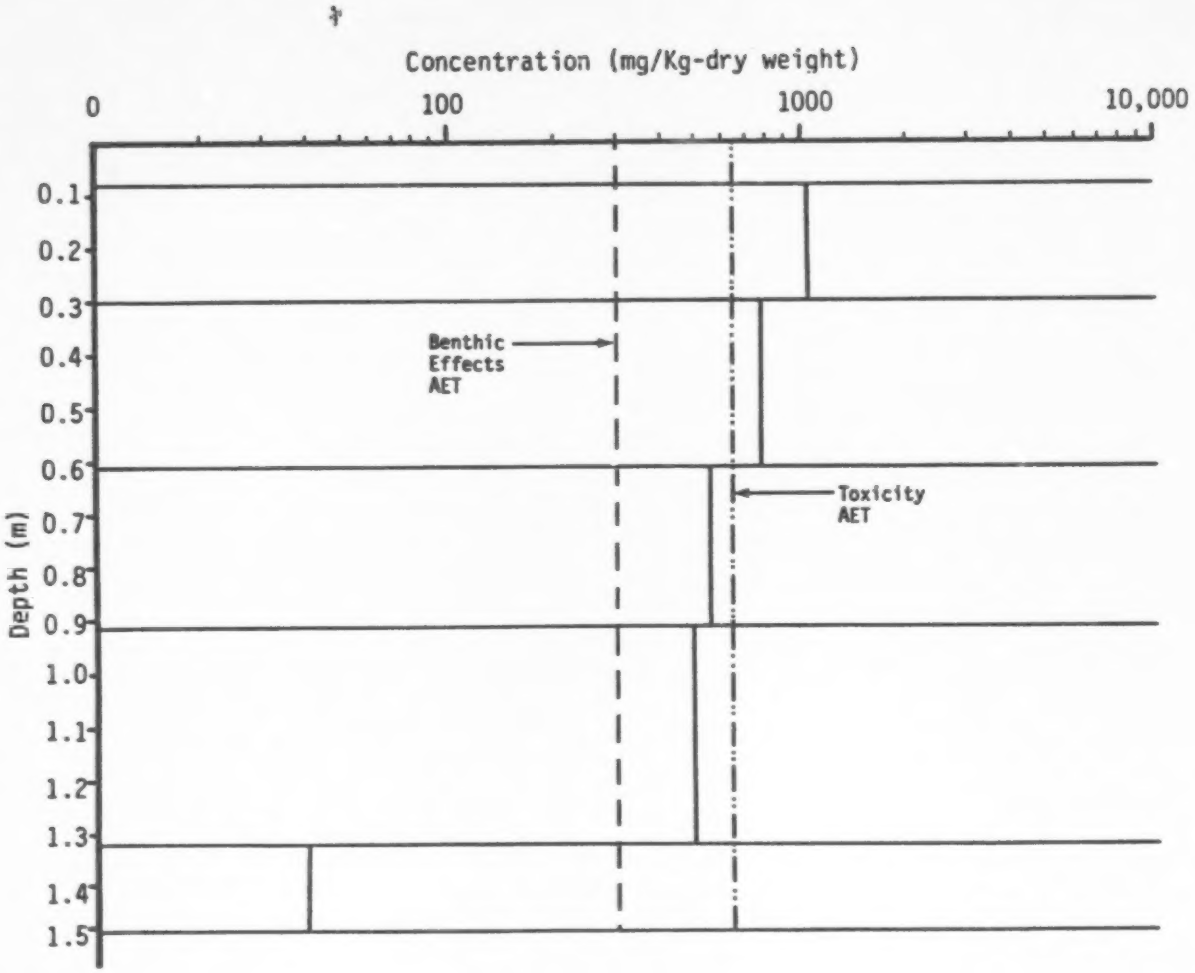


Figure 7.6.22

CONCENTRATION OF LEAD WITH DEPTH IN THE SEDIMENT
AT STATION CI-60, G05 NEAR THE HEAD OF CITY WATERWAY

Table 7.6.8

LEAD: SUMMARY OF LOADINGS FROM DISCHARGES TO THE CITY WATERWAY

Drain #	Drain Name	Flow (MGD) (Avg and Range) (# of Observations)	Period of Observations for Contaminant Concentrations	Concentration (µg/l) (Avg and Range) (# of Observations)	Loading (lbs/day) (Avg and Range)
CI-225	36" Concrete Stormdrain under 11th St. Bridge	0.051 (0.032-0.07) (n=2)	9/7/83	6 --- (n=1)	0.03 ---
CI-230	15th St. Stormdrain, 48" Concrete Pipe	0.17 (0.14-0.22) (n=3)	4/28/82-11/21/83	230 (3.5-650) (n=3)	0.33 (0.005-0.92)
CI-234	24" Wood Box Outfall at S. 21st Street	0.034 (0.03-0.037) (n=2)	9/7/83-11/21/83	23 (9-37) (n=2)	0.0065 (0.0023-0.010)
CI-243	21" Steel Pipe Stormdrain from RR Yard	0.37 (0.21-0.52) (n=2)	9/7/83-11/21/83	5.5 (1-10) (n=2)	0.017 (0.0031-0.031)
CI-245	18" Concrete Pipe Stormdrain from RR Yard	0.070 (0.05-0.09) (n=2)	9/7/83-11/21/83	1.0 --- (n=2)	0.00058 ---
CI-248	18" Concrete Pipe, 850 ft S of 15th Street	0.020 (0.01-0.03) (n=2)	9/7/83-11/21/83	3.5 (2-5) (n=2)	0.00058 (0.00033-0.00083)
CI-703	Concrete Pipe Drain at Harmon's Furniture	0.075 (0.06-0.09) (n=2)	9/7/83	2 --- (n=1)	0.0013 ---
CN-237	Nalley Valley Drain	3.6 (1.2-10.66) (n=8)	7/28/81-4/17/84	62 (3-360) (n=7)	1.9 (0.09-11)
CS-237	South Tacoma Drain	4.8 (2.58-10.98) (n=4)	2/16/82-9/7/83	33 (7-59) (n=2)	1.3 (0.28-2.36)
CW-254	30" Steel Stormdrain E. End of Wheeler-Osgood Waterway	0.29 (0.13-0.63) (n=4)	7/28/81-11/7/83	40 (18-80) (n=5)	0.097 (0.019-0.19)

NOTE: Lead has been analyzed for, but not detected in, the following drains: CI-208(1) and CI-244(1). The number in parentheses represents number of analyses. Detection limits are 1 µg/l.

waterway, providing 1.9 and 1.3 lb/day of lead, respectively. The 15th Street drain and the drain at the head of Wheeler-Osgood Waterway contributed substantially less lead (0.33 and 0.097 lb/day, respectively). This may be explained by the more limited drainage areas of the latter two storm drains.

7.6.9.3 Source Identification--

Storm Drains--The spatial gradient of lead contamination and the documented discharge of lead through the Nalley Valley and South Tacoma storm drains implicates these drains as the major sources of lead to City Waterway. These drains serve a large portion of the city of Tacoma, as illustrated in Figure 7.6.20. Particulate lead entering the waterway through these storm drains probably results largely from automobile emissions in the I-5 corridor and on residential streets.

Lead from automobile exhaust occurs in two basic forms: small particulate material (0.1-0.5 um), which remains airborne for large distances, and large particulate material (10-20 um), which is deposited within a few meters of the emission point onto the roadway, adjacent shoulders, or off-road areas (Pitt et al. 1981). While concentrations may vary dramatically, lead is consistently detected in urban stormwater runoff. Its concentration range resembles that of zinc and exceeds those of copper and chromium by an order of magnitude (Galvin and Moore 1982). Although no effort has been made to quantify lead released through automobile emissions in the Tacoma area (Nolan, J., personal communication), the I-5 corridor through Tacoma is expected to have lead concentrations similar to those of I-5 through Seattle [80-3,775 ug/L in highway runoff at two sites along I-5 in Seattle, Chui et al. (1981)]. The increase in automobile traffic in Tacoma over the years may help explain the steady increase in lead concentrations in the CI-60 sediment core of the head of City Waterway.

Other Sources--The Tacoma Spur coal gasification site is located approximately 1,000 ft southwest of the head of City Waterway. Hart-Crowser and Associates (1984) studied soil and groundwater conditions at this site. The maximum concentrations of lead measured during this study were 37.2 mg/kg in soil and 660 ug/L in groundwater. Possible sources of this contamination other than the coal gasification by-products include a coal- and wood-fired generating station, petroleum product storage tanks, and an abandoned gas station (Hart-Crowser and Associates 1984). These sources are located near the head of City Waterway. Groundwater contamination was attributed to the abandoned gas station, which provides a chronic input of lead to City Waterway via groundwater. This source is realtively insignificant compared to the amount of lead input via stormwater runoff.

Other potential sources of lead in sediments of City Waterway include spills of leaded fuels at the railroad yards and the petroleum bulk storage yards near the mouth of the waterway. The magnitude of these inputs cannot be quantified, but are not expected to be the large since waterway sediments did not show elevated lead concentrations in these areas.

Analyses by Norton and Johnson (1984) of lead in sediments offshore of American Plating showed concentrations ranging from 737 to 810 mg/kg. The concentrations were similar to those at the Tetra Tech 1984 station at the head of the waterway (CI-11). The proximity of American Plating to the 96-in storm drains does not permit adequate distinction between lead inputs from the drains and from American Plating. However, WDOE files give no indication that this company, or its predecessor, Puget Sound Plating, ever used lead in their processes. Thus, American Plating is not expected to have contributed lead contamination in the waterway.

7.6.9.4 Summary and Recommendation--

Lead contamination in sediments in City Waterway decreased markedly from the head to the mouth of the waterway, indicating a source near the head of the waterway. This source is believed to be the Nalley Valley and south Tacoma storm drains, both of which discharge at the head of the waterway. Lead loading from these two drains alone has been calculated at 3.2 lb/day, 87 percent of the total quantified loading of lead to the waterway. The source of lead in these drains is suspected to be urban runoff containing lead from automobile emissions and possible industrial and municipal discharges to the drainage system. A possible source of lead exists in Wheeler-Osgood Waterway.

Sources of lead into the storm drain systems should be investigated and corrective actions to reduce discharges should be implemented where feasible. Possible sources of lead to Wheeler-Osgood Waterway should be investigated.

7.6.10 Summary and Conclusions

The long history of industrialization in City Waterway by numerous small and moderate-size industries complicates source identification. Historical waste handling practices are not well documented, and, in many cases, present day waste production and disposal is not well quantified. Known information regarding identified or potential sources of compounds of concern to City Waterway are summarized in Figure 7.6.23. Several industries and storm drains have been identified as probable contributors of metals, PAH, or total organic carbon (TOC) to City Waterway. Sources of dibenzofuran are presumed to be the same as those for PAH. No sources were conclusively identified for PCBs, 1,2-dichlorobenzene, 1,4-dichlorobenzene, or 4-methylphenol.

The Nalley Valley and south Tacoma drains are the major contributors of many of the contaminants of concern to City Waterway. They are ongoing sources of all metals of concern in the waterway, contributing 87, 88, and 81 percent of the quantified loadings of lead, copper, and zinc, respectively. One or both of these drains is also the major historical and potentially ongoing source of organic material to the waterway. Finally, the two drains are probably also a major ongoing source of PAH to City Waterway.

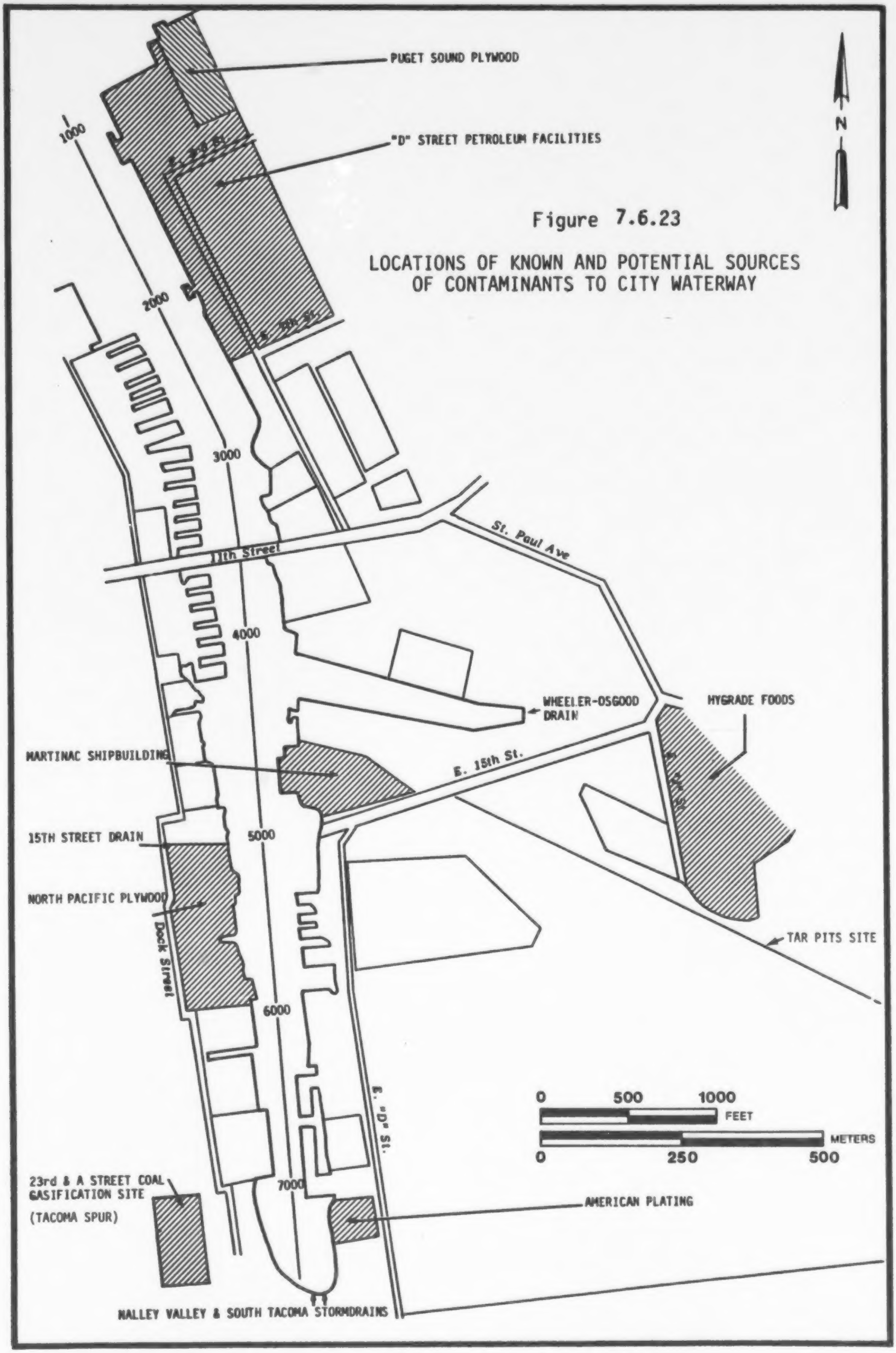


Figure 7.6.23

LOCATIONS OF KNOWN AND POTENTIAL SOURCES OF CONTAMINANTS TO CITY WATERWAY

Discharge from the 15th Street drain contributes metals and PAH to the waterway, but in much lower amounts than the two storm drains at the head of the waterway. The 15th Street drainage basin is much smaller and average flows are much lower.

Hygrade Foods and/or its predecessor, Carsten's Packing Company, appear to be responsible for historical organic enrichment in Wheeler-Osgood Waterway. Both were major dischargers of organic material. The potential of continuing periodic discharges from Hygrade Foods is possible, as is natural decay of accumulated organic debris in the anoxic basin. Storm drains to Wheeler-Osgood Waterway are sources of copper, lead, and zinc. There may be other sources of metals to the waterway as well. Possible sources of 4-methylphenol to the Wheeler-Osgood Waterway are groundwater from the Tar Pits, and degradation of wood chip debris in the sediments.

Martinac Shipbuilding, near the juncture between City and Wheeler-Osgood Waterways, is a probable source of copper and zinc to City Waterway. Sandblasting and use of antifouling paints are suspected contributors.

North Pacific Plywood, Puget Sound Plywood, the Tar Pits, and the Tacoma Spur (at 23rd and A Street) are all possible sources of 4-methylphenol to City Waterway. Additionally, the Tacoma Spur and possibly the Tar Pits site are potential ongoing sources of 4-methylphenol and LPAH through groundwater. Discharges from North Pacific Plywood may have occurred via groundwater or from spills of phenolic glues that entered the storm sewer leading to the 15th Street drain. Glue wastes from Puget Sound Plywood may be contributing to elevated sediment levels of 4-methylphenol seen near the mouth of City Waterway.

The D Street petroleum facilities contribute LPAH to the waterway via shallow groundwater seeping from the bank of the waterway. The problem has been ongoing for 12 yr, if not longer. No relationship can be established between the chemical contaminants in groundwater and the chemical contaminants in the sediments (Johnson and Norton 1985). The D Street petroleum facilities are not believed to be the source of HPAH seen in the sediments at the mouth of the waterway, although the actual source has not been definitively identified.

Investigations are necessary to determine the sources of the petroleum products observed in the storm drains near West Coast Grocery and in the vicinity of 15th Street. Potential sources include several old gasoline stations, a historical railroad roundhouse, and Chevron. A historical source of PAH that will probably never be quantified is spills and bilge pumping.

7.7 RUSTON-PT. DEFIANCE SHORELINE

7.7.1 Introduction

The Ruston-Pt. Defiance Shoreline study area extends along the southwest shore of Commencement Bay from the Point Defiance Zoo and Aquarium to the mouth of City Waterway. This area was the location of the original Tacoma settlement in the late 1800s and the site of the Tacoma Mill, the first lumber mill on Commencement Bay, which began cutting in 1869. Other industries which had been located on the Ruston-Pt. Defiance Shoreline include eight lumber companies, two grain elevator facilities, a lime company, a boat building operation, a fuel company, a cold storage company, and railroad freight warehouses (Ruckelshaus unpublished).

The Tacoma Smelter opened on the Ruston-Pt. Defiance Shoreline in 1889 as a lead smelter. It was modified for copper smelting about 1906 when it was bought by American Smelting and Refining Company (ASARCO). Lead smelting was discontinued in 1911. Copper refining facilities were built in 1913 and arsenic recovery systems were added in 1917 (Sims 1979). Facilities for production of sulfuric acid and sulfur dioxide were added in later years. Depressed metal prices led to closure of the metal refining facilities at ASARCO in 1978. The copper smelter was closed in the spring of 1985. Currently, only the arsenic trioxide plant is in operation; shutdown was expected before the summer of 1985 (Pierce, R., personal communication).

Other facilities currently operating on the Ruston-Pt. Defiance Shoreline are shown in Figure 7.7.1. They include the Pt. Defiance Ferry Terminal Slip, Tacoma Yacht Basin, City of Tacoma Fire Station No. 5 Pier, Continental Grain Company, Tacoma Elevator Wharf, and Tacoma North Sewage Treatment Plant (STP). Otherwise, much of the shoreline and area to the south is residential housing and small commercial establishments.

The Ruston-Pt. Defiance Shoreline has had several modifications to its waterfront as a result of dredge and fill operations. The peninsula enclosing the Tacoma Yacht Basin was formed by copper smelting slag placed under permits issued from 1917 to 1962. Slag was also used to build up the shoreline on which much of the ASARCO plant is now located. Between 55,000 and 90,000 yd^3 of the slag near the Tacoma Yacht Basin was removed and replaced with riprap under a 1977 permit. Other permits have been issued for fill operations to stabilize shoreline embankments. A summary of the dreding projects is presented in Table 7.7.1.

Locations of known discharges to the Ruston-Pt. Defiance Shoreline are shown in Figure 7.7.1. The only NPDES-permitted discharges are from ASARCO (RS-003, RS-004, and RS-005) and Tacoma North STP (RS-022). ASARCO's discharge permit includes limits for pH, oil and grease, and flow volume. The company has also been required to monitor arsenic, cadmium, copper, lead, and zinc discharges. Although the smelter has closed, there is still some discharge from these outfalls, primarily site runoff and noncontact cooling water (Pierce, R., personal communication). The Tacoma North STP has discharge permit limits for biochemical oxygen demand, total suspended

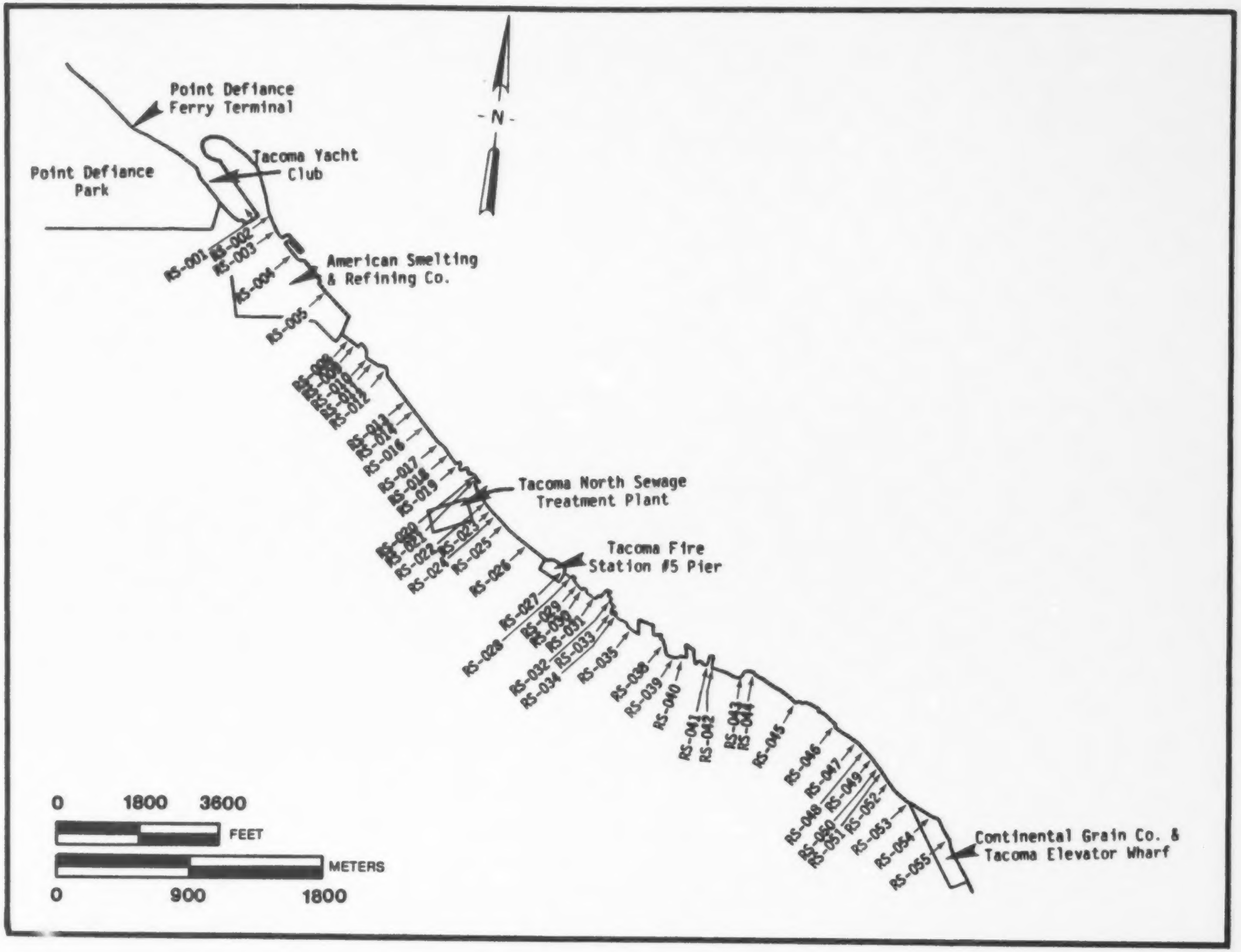


Figure 7.7.1

MAJOR INDUSTRIES AND DISCHARGES TO THE RUSTON SHORELINE

TABLE 7.7.1. SUMMARY OF DREDGING PROJECTS, RUSTON-PT. DEFIANCE SHORELINE

Year	Permitee	Quantity (yd^3)	Comments
1977	ASARCO	17,000	Slag fill
1980	Industrial Mineral Products	90,000	55,000 yd^3 dredged by 1980
1982	Crown Pacific Corporation	4,300	Dredge and fill
1983	ASARCO	850	Gravel fill
Unknown	Tacoma Metro Park District	Unknown	

Reference: U.S. Army Corps of Engineers dredging permits, as compiled by M. Ruckelshaus, WDOE.

solids, fecal coliform bacteria, and flow volume. Numerous storm drains discharge from the Ruston-Pt. Defiance Shoreline. The largest ones are a 60-in storm drain at Alder Street (RS-029), a 60-in storm drain 250 m northwest of McCarver Street (RS-039), and a 48-in drain 225 m northwest of McCarver Street (RS-040).

The locations of sediment chemistry sampling stations along Ruston-Pt. Defiance Shoreline, shown in Figure 7.7.2 include those sampled as part of the Superfund investigation, as well as all historical sampling sites. Eleven contaminants or groups of contaminants were designated as preliminary contaminants of concern on the Ruston-Pt. Defiance Shoreline. These contaminants and their respective areas of concern are

Organic Compounds

Aromatic hydrocarbons (Segments 1 and 2)
Dibenzofuran (Segment 1)
PCBs (Segment 2)
Phenols (Segment 1)
Chlorinated benzenes (Segment 1)

Inorganic Substances

Arsenic (Segments 1 and 2)
Cadmium (Segment 2)
Copper (Segments 1 and 2)
Lead (Segments 1 and 2)
Mercury (Segments 1 and 2)
Zinc (Segment 2)

Station RS-13 was the only station in Segment 1 designated to be of concern because of observed sediment toxicity or benthic effects. Biological data were not available for Station RS-15, but it was later determined to be a potential problem station because several chemical concentrations exceeded AET when normalized to percent fine-grained material or organic carbon content. No dry-weight concentrations exceeded AET at Station RS-15 and no source evaluations were conducted in this area. A potential problem area in Ruston-Pt. Defiance Shoreline Segment 3 was ultimately defined on the basis of AET values. This area had not been designated to be of preliminary concern and no source evaluations were conducted.

Arsenic, copper, lead, and mercury are listed as of preliminary concern in Segment 1 (Station RS-13) and source evaluations were conducted for them. It was later determined that concentrations of these contaminants did not exceed AET at Station RS-13. Concentrations of all other chemicals listed above as of preliminary concern were determined to exceed AET in their respective areas. Other contaminants whose concentrations were ultimately determined to exceed AET but were not subjected to source evaluations include

Substance	Station Where AET (dry weight) Exceeded
Dichlorobenzenes	RS-18
N-nitrosodiphenylamine	RS-18, RS-24
Methylphenols	RS-13, RS-18
Phthalate esters	RS-16
Dibenzofuran	RS-16, RS-18, RS-21
Antimony	RS-16, RS-17, RS-18, RS-19, RS-21, RS-24
Nickel	RS-17, RS-18, RS-21

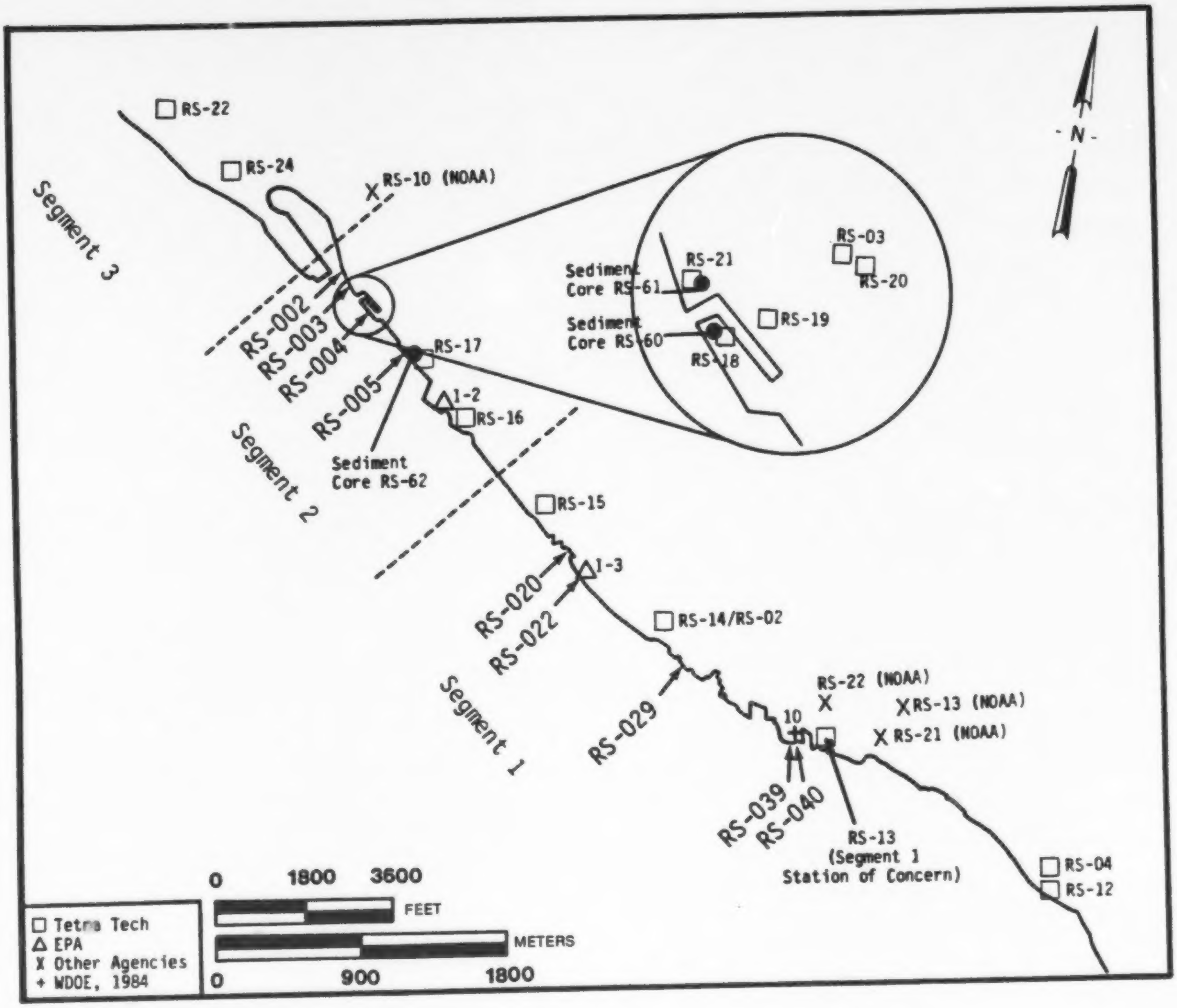


Figure 7.7.2

SURFICIAL SEDIMENT STATIONS AND SEDIMENT CORE LOCATIONS FROM ALL STUDIES ON THE RUSTON SHORELINE

Antimony and nickel concentrations normalized to percent fine-grained material exceeded AET at most stations in Segment 2. These substances probably derive from the same sources as the other metals in Segment 2. Concentrations of several tentatively identified compounds were also determined to exceed AET in either Segment 1 or 2 [i.e., 1-methyl(2-methylethyl)benzene, biphenyl, dibenzothiophene, methylphenanthrenes, retene, and methylpyrenes]. These substances are not discussed further, but likely derive from similar sources as the PAH.

Average mass flux estimates were not calculated for any of the priority contaminants along the Ruston-Pt. Defiance Shoreline because of major uncertainties concerning the appropriate area of deposition required for the analysis. In any case, spatial distributions clearly indicate the major sources of contaminants in Segment 2. There are insufficient data with which to determine sources of contaminants for the hot spot around Station RS-13 in Segment 1.

7.7.2 Spatial Distribution

The distributions of contaminants of concern in surficial sediments of the Ruston-Pt. Defiance Shoreline are shown in Figures 7.7.3-7.7.14. All contaminants showed similar gradients, with highest concentrations at Stations RS-17, 18, 21, and/or RS-13.

The metals, PAH, and dibenzofuran typically showed the highest concentrations normalized to dry weight, TOC, or percent fine-grained material at Stations RS-17, 18, and 21. Concentrations of the contaminants in this area were typically one to two orders of magnitude higher than those elsewhere along the Ruston-Pt. Defiance Shoreline. Of the three stations adjacent to the ASARCO shoreline (RS-17, 18, and 21), none had the highest concentrations for all contaminants. Station RS-17 had the highest arsenic concentrations; Station RS-18 had the highest cadmium, lead, mercury, and PAH concentrations; and Station RS-21 had the highest copper and zinc concentrations.

PCB concentrations were elevated (>500 ug/kg) at several Tetra Tech stations in Segment 2 (including RS-16, 17, and 21) and at one station in Segment 1 (NOAA station RS-13, a different site than the Tetra Tech RS-13).

Elevated concentrations of PAH and dibenzofuran, normalized to both dry weight and organic carbon, were found at Tetra Tech Station RS-13, in Segment 1. Lead, mercury, and zinc concentrations were also elevated at Station RS-13.

The phenols and chlorinated benzenes were designated to be of concern along the Ruston-Pt. Defiance Shoreline at Station RS-13. Within these two contaminant groups, 2-methylphenol and 1,4-dichlorobenzene showed the most apparent increased concentrations at this station. The spatial distributions of these compounds are shown in Figures 7.7.12 and 7.7.13. Both showed increased concentrations at Station RS-13, the site nearest the

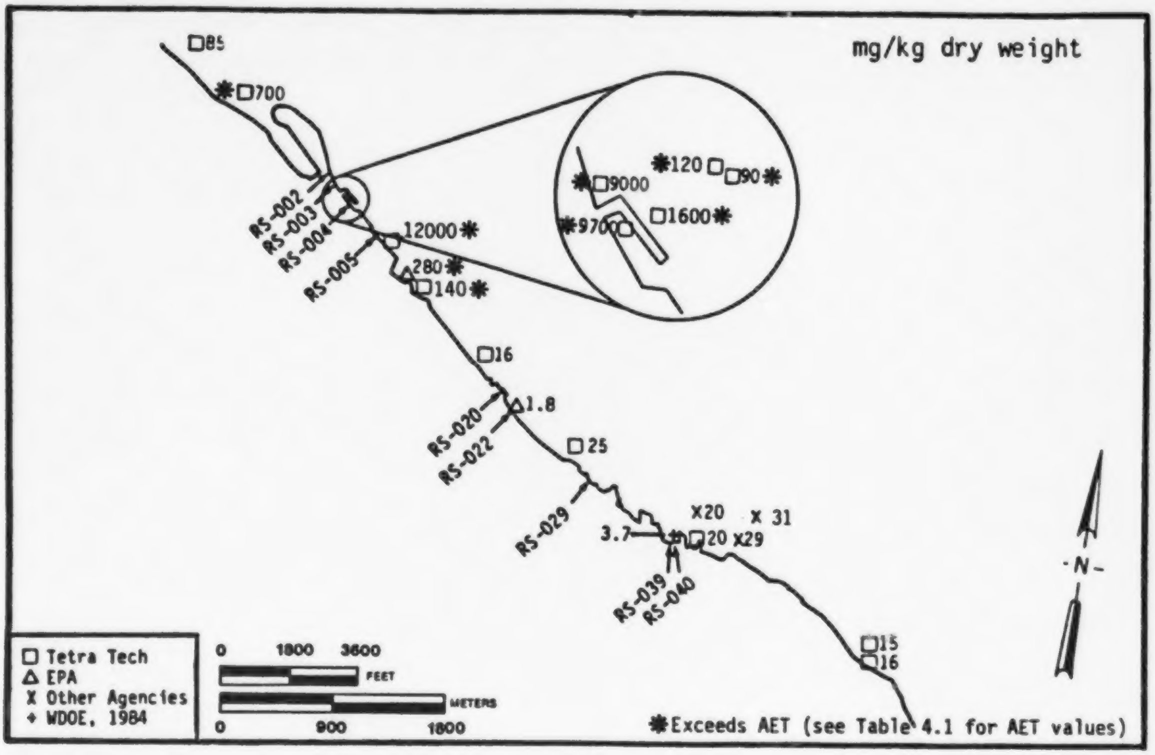


Figure 7.7.3

CONCENTRATIONS OF ARSENIC IN THE
SURFICIAL SEDIMENTS OF THE RUSTON SHORELINE

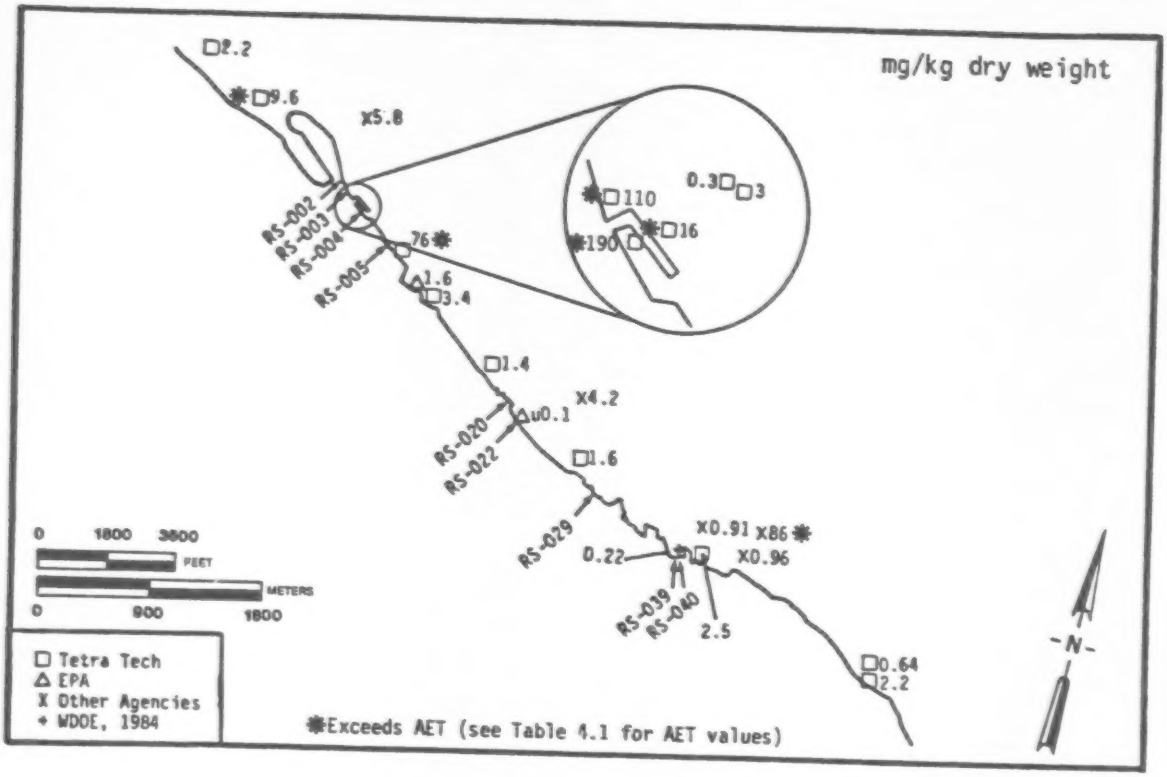


Figure 7.7.4

CONCENTRATIONS OF CADMIUM IN THE SURFICIAL SEDIMENTS OF THE RUSTON SHORELINE

u = undetected at concentration shown

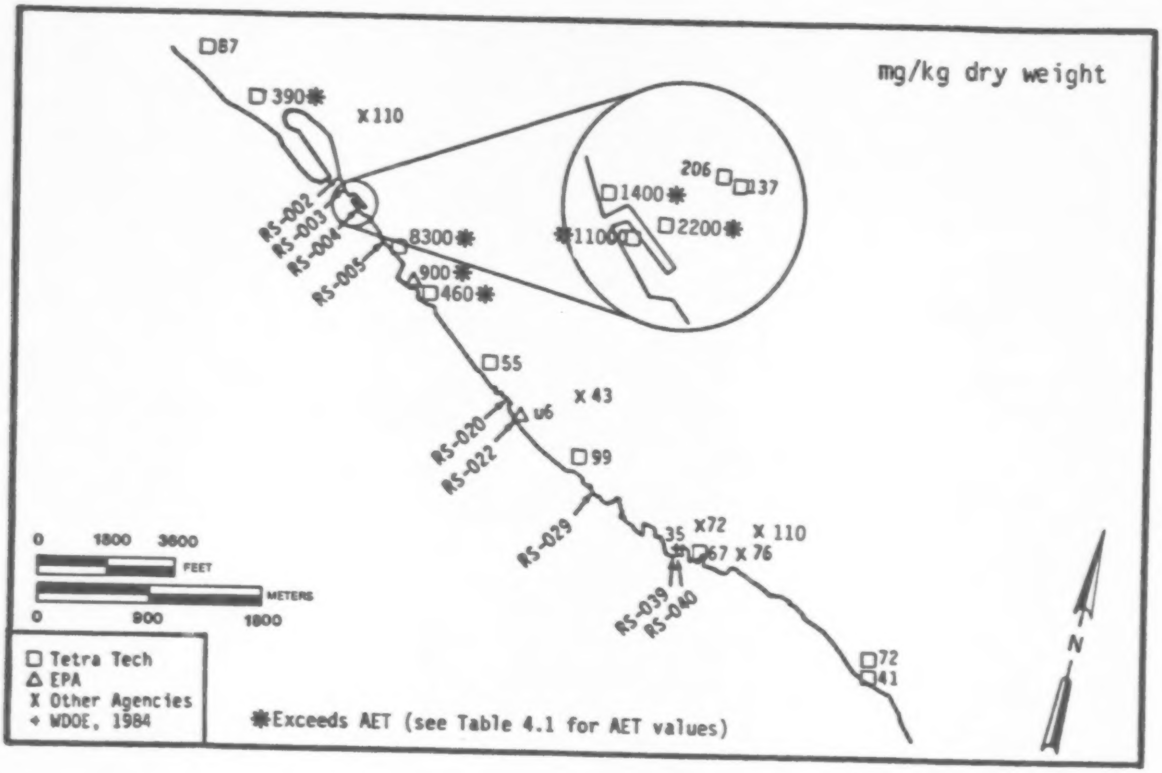


Figure 7.7.5

CONCENTRATIONS OF COPPER IN THE
SURFICIAL SEDIMENTS OF THE RUSTON SHORELINE

u = undetected at concentration shown

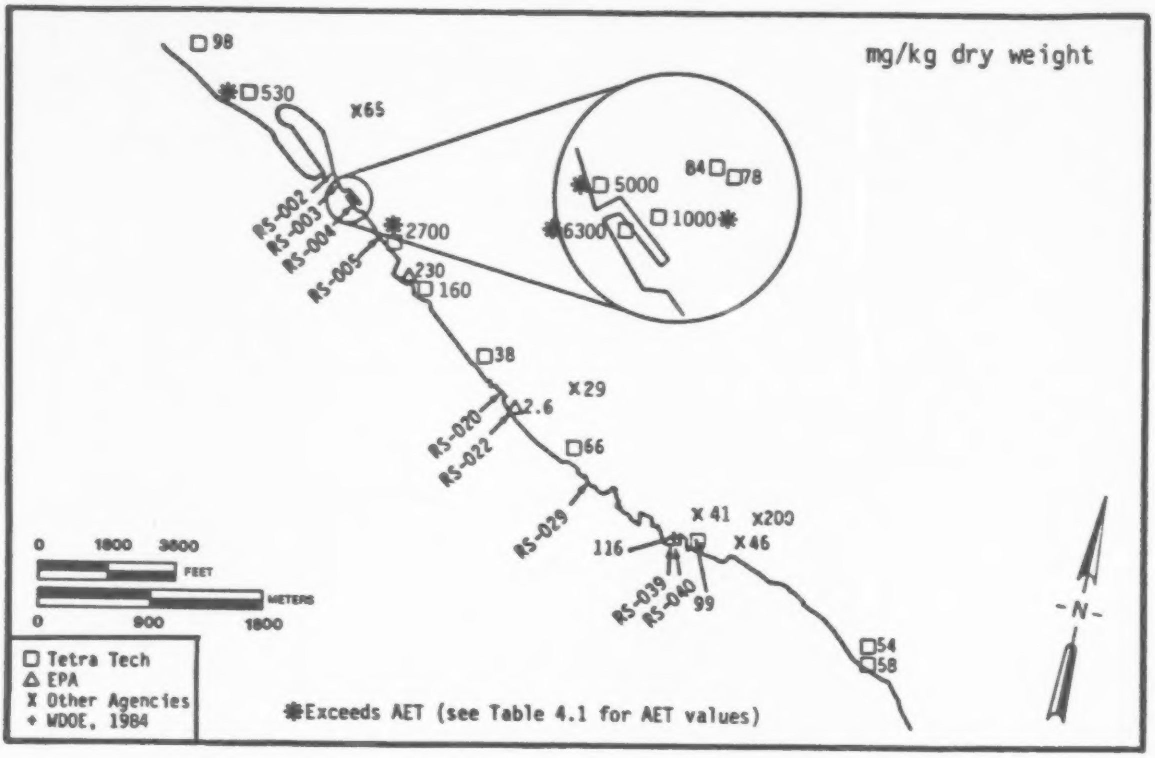


Figure 7.7.6

CONCENTRATIONS OF LEAD IN THE
SURFICIAL SEDIMENTS OF THE RUSTON SHORELINE

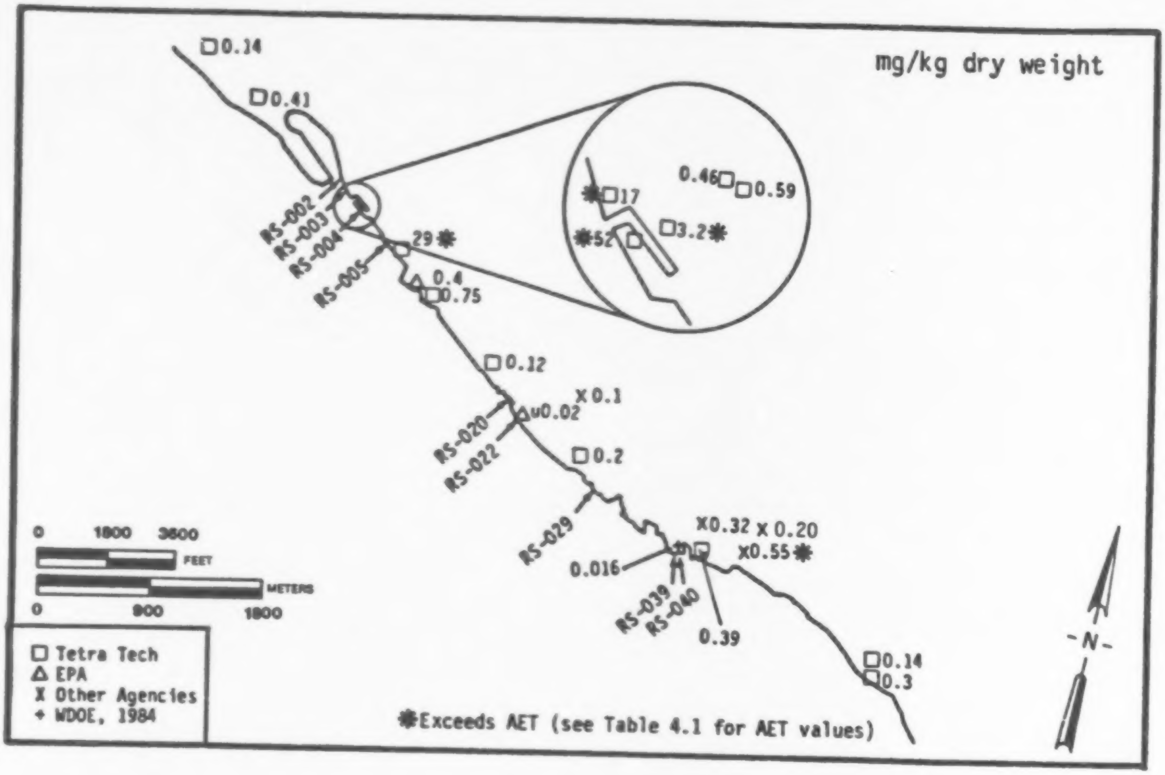


Figure 7.7.7

CONCENTRATIONS OF MERCURY IN THE SURFICIAL SEDIMENTS OF THE RUSTON SHORELINE

u = undetected at concentration shown

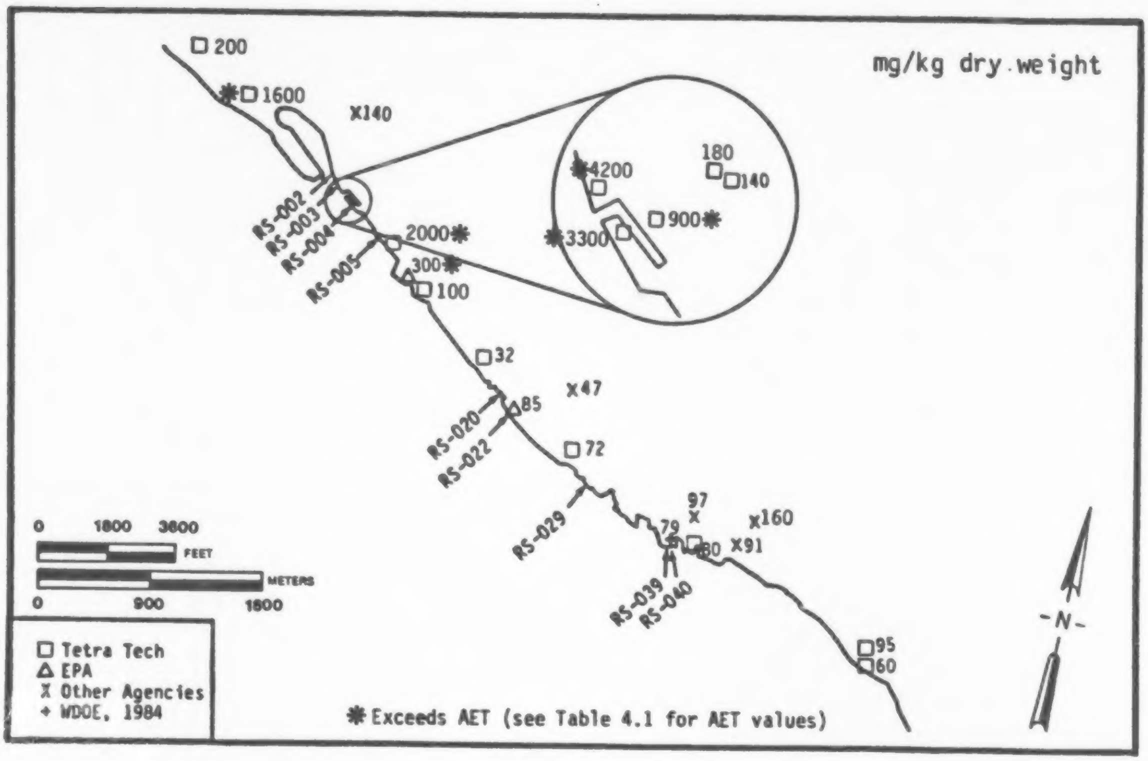


Figure 7.7.8

CONCENTRATIONS OF ZINC IN THE SURFICIAL SEDIMENTS OF THE RUSTON SHORELINE

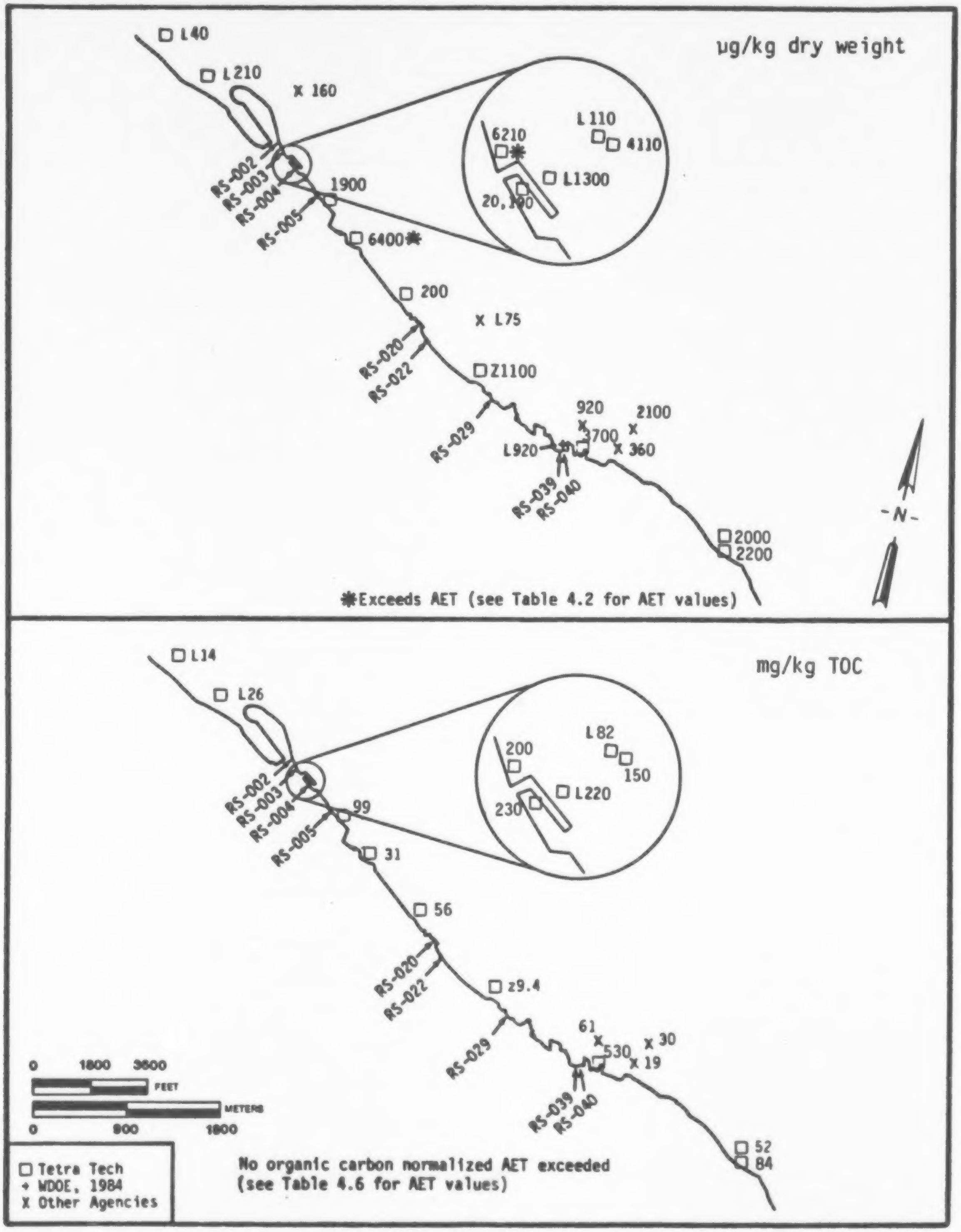


Figure 7.7.9

CONCENTRATIONS OF LOW MOLECULAR WEIGHT PAH IN THE SURFICIAL SEDIMENTS OF THE RUSTON SHORELINE

L = At least one of the components of the group was undetected, sum included the detection limit.

Z = Data corrected for blank.

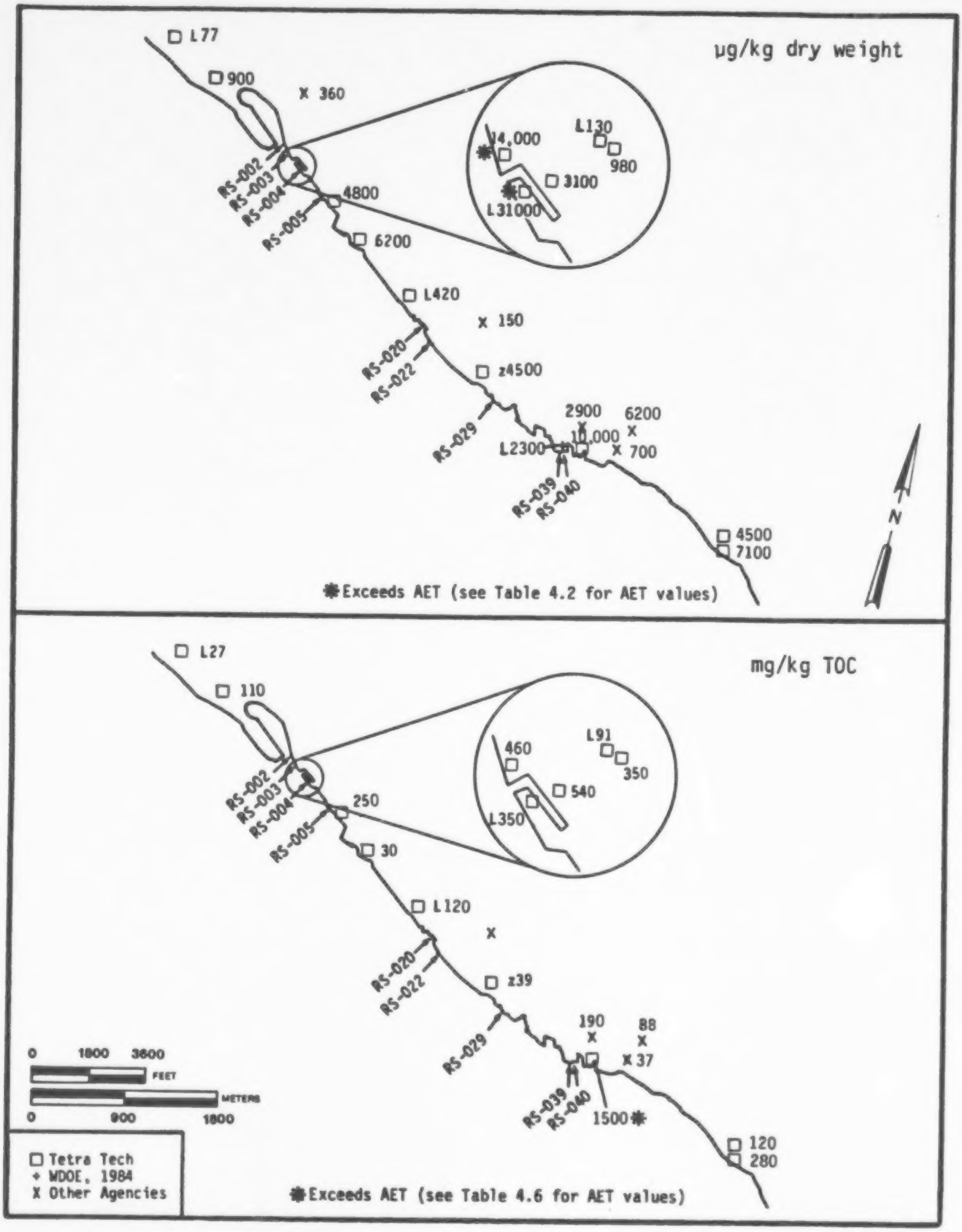


Figure 7.7.10

CONCENTRATIONS OF HIGH MOLECULAR WEIGHT PAH IN THE SURFICIAL SEDIMENTS OF THE RUSTON SHORELINE

u = undetected at concentration shown
z = data corrected for blank

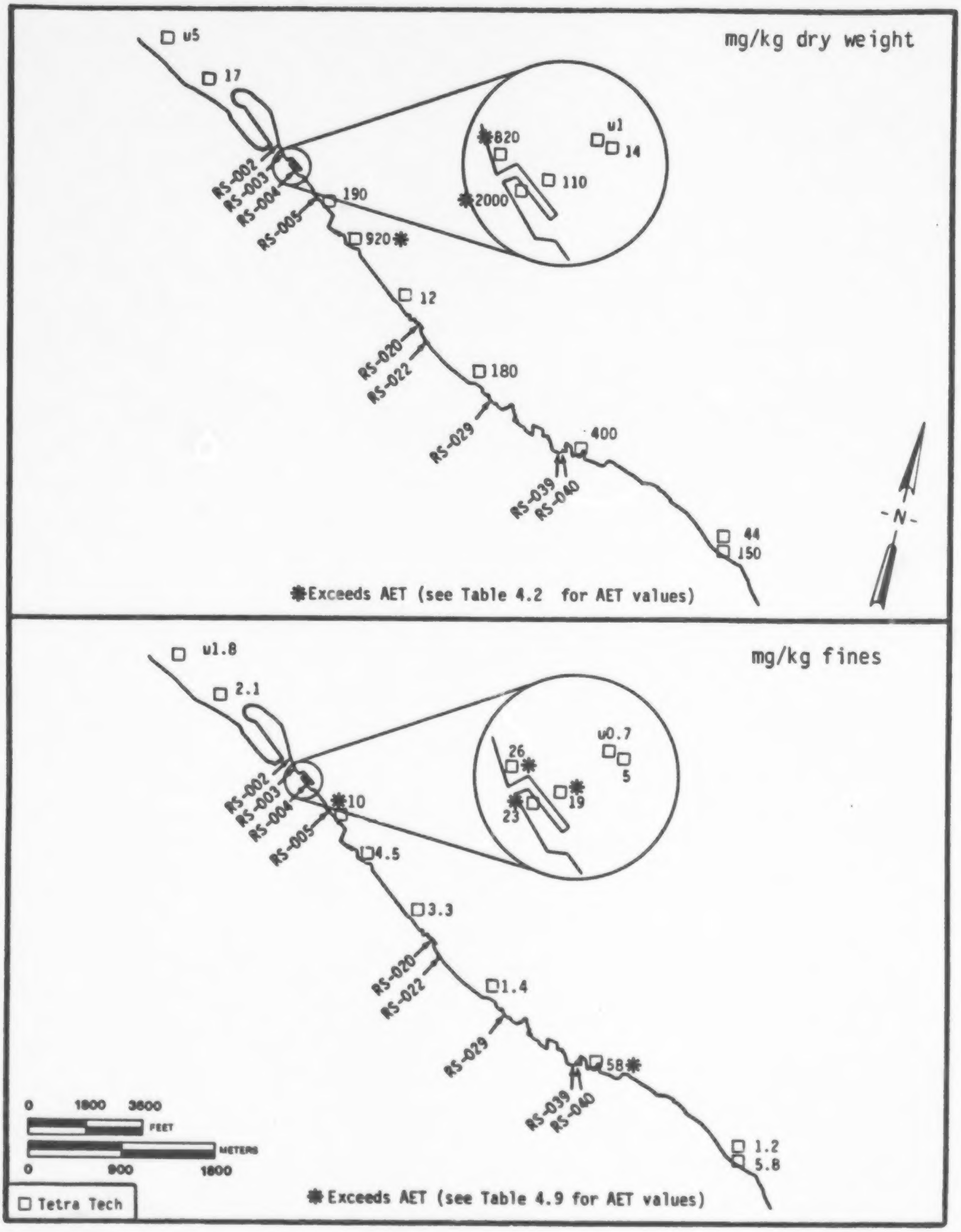


Figure 7.7.11

CONCENTRATIONS OF DIBENZOFURAN IN THE SURFICIAL SEDIMENTS OF THE RUSTON SHORELINE

u = undetected at concentration shown

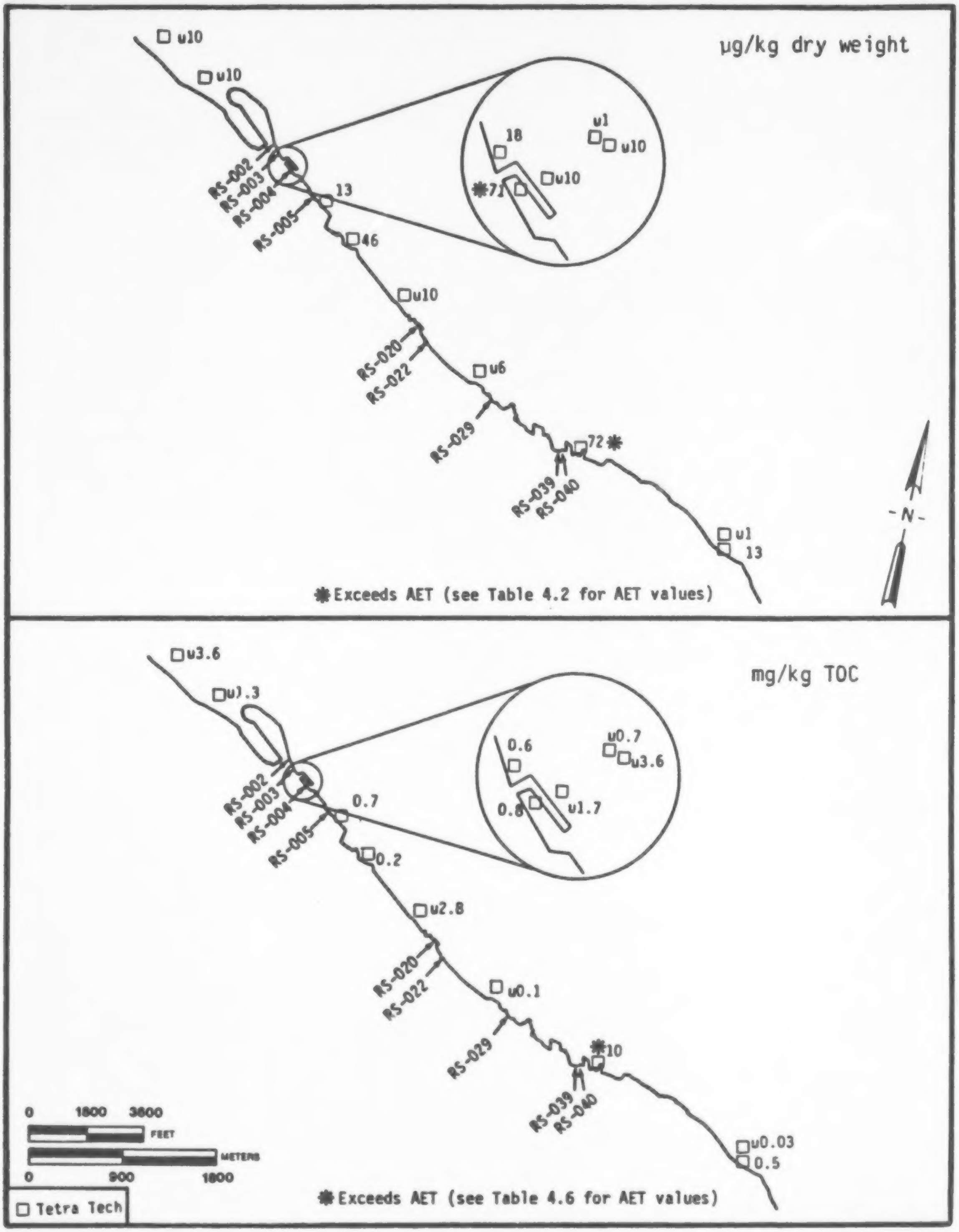


Figure 7.7.12

CONCENTRATIONS OF 2-METHYL PHENOL IN THE
SURFICIAL SEDIMENTS OF THE RUSTON SHORELINE

u = undetected at concentration shown

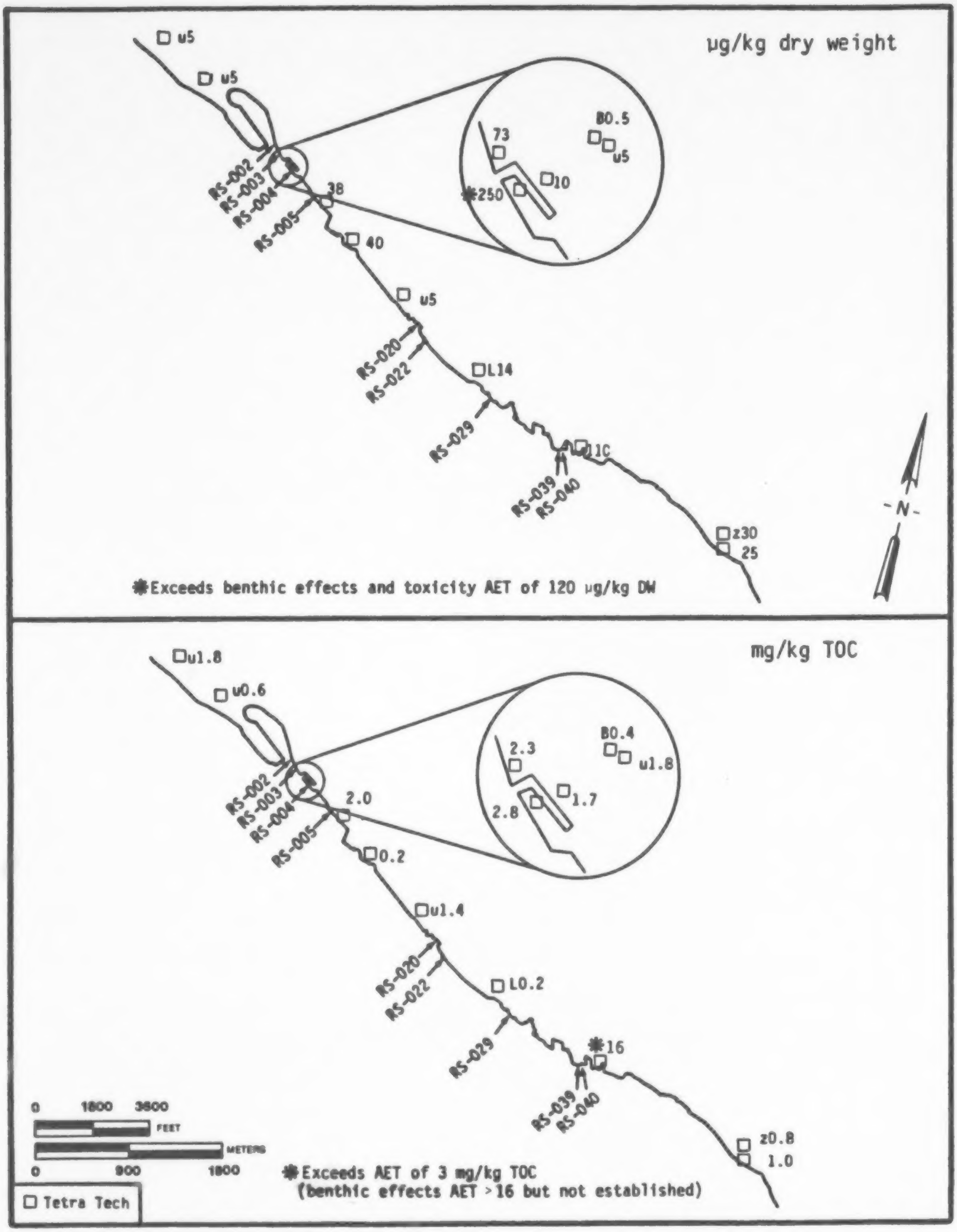


Figure 7.7.13

CONCENTRATIONS OF 1,4-DICHLOROBENZENE IN THE SURFICIAL SEDIMENTS OF THE RUSTON SHORELINE

u = undetected at concentration shown
B = blank contribution greater than observed value
z = data corrected for blank

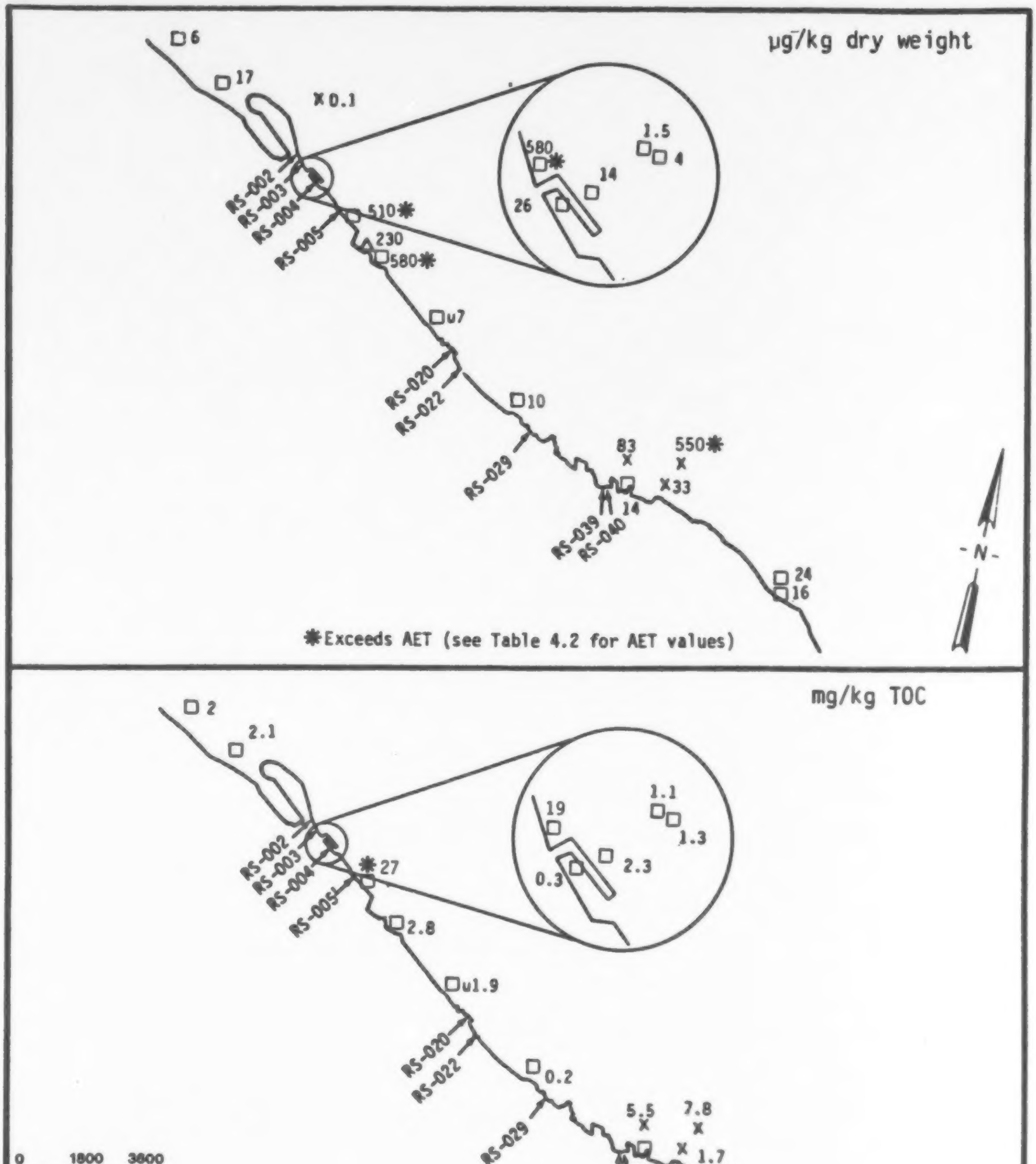


Figure 7.7.14

CONCENTRATIONS OF PCBs IN THE
SURFICIAL SEDIMENTS OF THE RUSTON SHORELINE

u = undetected at concentration shown

RS-039 and RS-040 outfalls. A second area of elevated 1,4-dichlorobenzene concentrations was detected at Station RS-18 near the RS-004 outfall.

Sediment cores were not taken in Segment 1. Therefore, assessment of historical trends in contaminant input was not possible. Three sediment core samples were taken in Segment 2, one each near the three major outfalls in this segment. The concentrations with depth of selected priority contaminants are shown in Tables 7.7.2 and 7.7.3.

Similar vertical patterns of PAH and dibenzofuran contamination occurred in all three cores. Concentrations in the upper horizon were consistently higher than those in the lower horizons. Different vertical patterns of PCB and metals contamination occurred in the three cores. PCB concentrations increased with depth at Station RS-60, decreased with depth at Station RS-61, and were the same in both horizons at Station RS-62. Metals concentrations at Station RS-60 remained constant or decreased slightly with depth. At Station RS-61, there was a consistent increase in concentration in Horizon 1 (0-0.038 m) followed by an approximate 1.5- to 5-fold decrease in concentration below that depth. A subsurface increase in concentration occurred in Horizon 4 (0.15-0.41 m) for most compounds, although zinc showed a subsurface maximum in Horizon 5 (0.41-0.44 m). There was little consistency in compound concentrations at Station RS-62. Arsenic, zinc, and cadmium concentrations were higher in the upper horizon (0-0.051 m), while mercury, copper, and lead concentrations were higher in the lower horizon (0.051-0.23 m).

Each of the three sediment cores was located near one of three major outfalls. The differences among cores in vertical gradients of metals and PCB concentrations probably reflect differential input of these contaminants from the various outfalls. Discharge RS-005 historically was a deep water outfall (exact dates of operation were not confirmed), which may explain the lower metals concentrations in the lower horizon of sediment core RS-62. The differences in vertical gradients among cores also suggest that deposition of airborne particulates in the bay is not the major source of the observed metals and PCB contamination. If this were the case, similar vertical patterns of contamination would be expected in each core.

7.7.3 Loading Estimates

Loading estimates were available for five outfalls on the Ruston-Pt. Defiance Shoreline. These outfalls, for which flows have been measured, include RS-003, RS-004, and RS-005 (the ASARCO outfalls); RS-022 (the Tacoma North STP outfall); and RS-040 (a 48-in city storm drain near McCarver Street). Loading estimates for RS-003, RS-004, and RS-005 do not include the discharge monitoring data from ASARCO's NPDES permit, only sampling data from industrial survey inspections.

7.7.3.1 Organic Compounds--

Analyses for organic compounds in this area are limited. Available data are shown in Table 7.7.4.

Table 7.7.2

CONCENTRATIONS OF ORGANIC COMPOUNDS WITH DEPTH IN THE SEDIMENT

	Contaminant			
	Low Molecular Weight PAH	High Molecular Weight PAH	Dibenzofuran	Total PCBs
Sediment Core RS-60, B01				
Horizon 1 (0-0.038 m)	6,000[a]	19,800[a]	410	760
Horizon 2 (0.038-0.127 m)	4,160	17,280[a]	140	1,500
Sediment Core RS-61, B01				
Horizon 1 (0-0.038 m)	10,260[a]	22,420[a]	890[a]	2,400
Horizon 2 (0.038-0.11 m)	4,620	21,420[a]	330	540
Horizon 3 (0.11-0.15 m)	980	4,000	61	360
Horizon 4 (0.15-0.41 m)	2,500	12,750[a]	200	410
Horizon 5 (0.41-0.44 m)	710	L 2,790	64	U 140
Sediment Core RS-62, B01				
Horizon 1 (0-0.051 m)	4,140	16,380[a]	200	340
Horizon 2 (0.051-0.23 m)	1,900	7,220	110	340

Concentrations as ug/kg dry weight
U = undetected at concentration shown
L = less than

[a] Value exceeds toxicity or benthic AET.

Table 7.7.3

CONCENTRATIONS OF ARSENIC AND METALS WITH DEPTH IN THE SEDIMENT

	Contaminant[a]					
	Arsenic	Mercury	Copper	Lead	Zinc	Cadmium
Sediment Core RS-60, B01						
Horizon 1 (0-0.038 m)	6,200	6.2	14,200	4,280	2,520	77
Horizon 2 (0.038-0.127 m)	4,400	5	14,600	3,450	2,780	56
Sediment Core RS-61, B01						
Horizon 1 (0-0.038 m)	20,000	6.2	35,800	10,400	9,160	282
Horizon 2 (0.038-0.11 m)	2,850	4.2	9,110	2,040	4,060	36
Horizon 3 (0.11-0.15 m)	2,350	0.6	4,720	2,180	7,010	24
Horizon 4 (0.15-0.41 m)	4,300	8.5	12,700	3,860	5,580	56
Horizon 5 (0.41-0.44 m)	2,800	2.8	5,170	3,070	12,900	31
Sediment Core RS-62, B01						
Horizon 1 (0-0.051 m)	29,500	13	4,110	3,300	2,950	231
Horizon 2 (0.051-0.23 m)	5,800	21	21,200	3,640	2,470	60

Concentrations as mg/kg dry weight.

[a] Concentrations of all contaminants listed exceed toxicity and benthic AET in every horizon shown.

Table 7.7.4

ORGANIC COMPOUNDS: SUMMARY OF LOADINGS FROM DISCHARGES ALONG THE RUSTON SHORELINE

Drain #	Drain Name	Flow (MGD) (Avg. and Range) (# of Observations)	Period of Observations for Contaminant Concentrations	Concentration (ug/l) (Avg. and Range) (# of Observations)	Loading (lbs/day) (Avg. and Range)
LOW MOLECULAR WEIGHT					
RS-022	Tacoma North Sewage Outfall	4.8 --- (n=1)	6/30/79-9/14/81	3.9 (2.1-5) (n=3)	1.16 (0.084-0.20)
On two occasions, LPAH have been analyzed for but not detected in RS-040. Detection limits was 10 ug/l. Compounds detected in RS-022 included acenaphthene, naphthalene, fluorene, phenanthrene, and anthracene.					
HIGH MOLECULAR WEIGHT PAH					
RS-022	Tacoma North Sewage Outfall	4.8 --- (n=1)	6/30/79-9/14/81	13 (12-15) (n=2)	0.52 (0.48-0.60)
On two occasions, HPAH have been analyzed for but not detected in RS-040. Detection limits ranged from 10 to 20 ug/l. Compounds detected in RS-022 included chrysene, benzo(k)fluoranthene, benzo(b)fluoranthene, pyrene, fluorantehene, and dibenzo(a,h)anthracene.					
CHLORINATED BENZENES					
RS-022	Tacoma North Sewage Outfall	4.8 --- (n=1)	6/30/79-9/14/81	19 (2-35) (n=2)	0.76 (0.080-1.4)
On two occasions, chlorinated benzenes have been analyzed for but not detected in RS-040. Detection limits were 10 ug/l. Compounds detected in RS-022 included 1,2-dichlorobenzene, 1,3-dichlorobenzene, and hexachlorobenzene.					
TOTAL PHENOLS					
RS-022	Tacoma North Sewage Outfall	4.8 --- (n=1)	6/30/79-9/14/81	L 14 (L 10-18) (n=2)	L 0.56 (0.40-0.72)
On two occasions, phenols have been analyzed for but not detected in RS-040. Detection limits were from 30 to 60 ug/l. Compounds detected in RS-022 were phenol and pentachlorophenol.					

7.7.3.2 Inorganic Compounds--

Loading estimates of metals to the waters off the Ruston-Pt. Defiance Shoreline are shown in Tables 7.7.5-7.7.9. Highest concentrations of these contaminants were found at the ASARCO south outfall (RS-005). Loadings from this outfall were an order of magnitude higher than those from any other outfall. The next highest loadings were estimated for the ASARCO middle outfall (RS-004). Arsenic, copper, and zinc were the three major contaminants in discharges from the ASARCO plant. Arsenic loadings were approximately three times those of copper and four times those of zinc. Because the ASARCO outfall discharges have not been analyzed for mercury, corresponding loading data were not available.

7.7.4 Source Identification

Spatial distribution of contamination in the surficial sediments of the Ruston-Pt. Defiance Shoreline indicates two areas of elevated concentrations for the contaminants of concern. The first is located in Segment 2 adjacent to the property owned by ASARCO. Metals, PAH, and PCBs have been designated as contaminants of concern and all showed elevated concentrations within this area. A second site of elevated contaminant concentrations is at Station RS-13 in Segment 1. Sediments from this station had elevated concentrations of PAH, dibenzofuran, 2-methylphenol, and 1,4-dichlorobenzene relative to those from other stations in Segment 1. Spatial gradients of contamination are insufficient to support conclusive identification of major sources of metals in Segment 1. The two areas of elevated contaminant concentrations are discussed individually below.

7.7.4.1 Ruston-Pt. Defiance Shoreline Segment 2 - ASARCO--

The ASARCO facility was built as a lead smelter in 1889 and reconstructed as a copper smelter in 1906 when it was bought by the American Smelting and Refining Company. Over the years, copper smelting and refining, nickel extraction, and arsenic production occurred. The economics of production determined which activities took place. The ASARCO plant was one of the few facilities in the world that smelt ore highly contaminated with materials such as sulfur and arsenic. Much of this ore originated in the Philippines and Central America. The plant operated on consignment, mixing and smelting batches of material for specific customers. With changing markets in copper and other metals, production at the plant has steadily decreased over the past 5 yr.

In January, 1985, production of metallic arsenic operations at the ASARCO plant were discontinued. Only arsenic trioxide is produced at the present time. Prior to January, 1985, production activities included copper smelting, sulfur dioxide and sulfuric acid production, and elemental arsenic and arsenic trioxide production. For economic reasons, copper refining and nickel extraction had ceased some years earlier. Arsenic trioxide is currently produced from the residual arsenic concentrates on the plant site. It used to be produced as a by-product of the copper smelting process. Arsenic dust was recovered from the roasters, furnace, and converters,

Table 7.7.5

ARSENIC: SUMMARY OF LOADINGS FROM DISCHARGES ALONG THE RUSTON SHORELINE

Drain #	Drain Name	Flow (MGD) (Avg. and Range) (# of Observations)	Period of Observations for Contaminant Concentrations	Concentration (ug/l) (Avg. and Range) (# of Observations)	Loading (lbs/day) (Avg. and Range)
RS-003	ASARCO North Outfall	0.48 (0.32-0.63) (n=2)	11/18/75-9/15/82	78 (8-150) (n=5)	0.31 (0.032-0.60)
RS-004	ASARCO Middle Outfall	1.2 (1.0-1.4) (n=2)	11/18/75-9/15/82	7,800 (38-18,500) (n=6)	78 (0.38-185)
RS-005	ASARCO South Outfall	3.4 (1.5-4.3) (n=3)	11/18/75-9/15/82	14,000 (260-80,000) (n=8)	400 (7.4-2,300)
RS-022	Tacoma North Sewage Outfall	4.8 --- (n=1)	6/30/79-4/28/82	39 (6.5-110) (n=4)	1.6 (0.26-4.4)
RS-040	48-inch Concrete Pipe	0.91 (0.64-1.2) (n=2)	9/14/81-4/28/82	9 (5-13) (n=2)	0.068 (0.038-0.10)

NOTE: Arsenic has been detected in RS-020 (5 ug/l) and in RS-070 (20-3,800 ug/l); however, no flow data are available from which to calculate loadings.

Table 7.7.6

CADMIUM: SUMMARY OF LOADINGS FROM DISCHARGES ALONG THE RUSTON SHORELINE

Drain #	Drain Name	Flow (MGD) (Avg. and Range) (# of Observations)	Period of Observations for Contaminant Concentrations	Concentration (ug/l) (Avg. and Range) (# of Observations)	Loading (lbs/day) (Avg. and Range)
RS-003	ASARCO North Outfall	0.48 (0.32-0.63) (n=2)	2/24/81-9/15/82	L 3 (1-L 5) (n=2)	L 0.012 (0.0040-L 0.020)
RS-004	ASARCO Middle Outfall	1.2 (1.0-1.4) (n=2)	11/18/75-9/15/82	92 (50-170) (n=4)	0.92 (0.50-1.7)
RS-005	ASARCO South Outfall	3.4 (1.5-4.3) (n=3)	11/18/75-9/15/82	360 (30-1,700) (n=7)	10 (0.85-48)
RS-022	Tacoma North Sewage Outfall	4.8 --- (n=1)	6/30/79-4/28/82	2.3 (0.87-5) (n=3)	0.092 (0.035-0.20)
RS-040	48-inch Concrete Pipe	0.91 (0.64-1.2) (n=2)	4/28/82	2 --- (n=1)	0.015 ---

NOTE: Cadmium has been detected in RS-020 (30 ug/l) and in RS-070 (32 ug/l); however, no flow data are available from which to calculate loadings.

Table 7.7.7

COPPER AND MERCURY: SUMMARY OF LOADINGS FROM DISCHARGES ALONG THE RUSTON SHORELINE

Drain #	Drain Name	Flow (MGD) (Avg. and Range) (# of Observations)	Period of Observations for Contaminant Concentrations	Concentration (ug/l) (Avg. and Range) (# of Observations)	Loading (lbs/day) (Avg. and Range)
			COPPER		
RS-003	ASARCO North Outfall	0.48 (0.32-0.63) (n=2)	11/18/75-9/15/82	290 (40-700) (n=5)	1.2 (0.16-2.8)
RS-004	ASARCO Middle Outfall	1.2 (1.0-1.4) (n=2)	11/18/75-9/15/82	3,300 (60-6,700) (n=5)	33 (0.6-67)
RS-005	ASARCO South Outfall	3.4 (1.5-4.3) (n=3)	11/18/75-9/15/82	4,200 (150-15,500) (n=8)	120 (4.3-440)
RS-022	Tacoma North Sewage Outfall	4.8 --- (n=1)	6/30/79-4/28/82	52 (32-65) (n=4)	2.1 (1.3-2.6)
RS-040	48-inch Concrete Pipe	0.91 (0.64-1.2) (n=2)	4/28/82	10 --- (n=1)	0.076 ---

NOTE: Copper was analyzed for but not detected in RS-020. Detection limit was 50 ug/l. Copper has been found in RS-070 on four occasions (160-380 ug/l); however, no flow data are available from which to calculate loading.

MERCURY

RS-022	Tacoma North Sewage Outfall	4.8 --- (n=1)	8/20/79-4/28/82	1.4 (0.36-3.5) (n=3)	0.056 (0.014-0.14)
RS-040	48-inch Concrete Pipe	0.91 (0.64-1.2) (n=2)	9/14/81-4/28/82	0.35 (0.26-0.43) (n=2)	0.0027 (0.0020-0.0033)

Table 7.7.8

LEAD: SUMMARY OF LOADINGS FROM DISCHARGES ALONG THE RUSTON SHORELINE

Drain #	Drain Name	Flow (MGD) (Avg. and Range) (# of Observations)	Period of Observations for Contaminant Concentrations	Concentration (ug/l) (Avg. and Range) (# of Observations)	Loading (lbs/day) (Avg. and Range)
RS-003	ASARCO North Outfall	0.48 (0.32-0.63) (n=2)	2/24/81	71 --- (n=1)	0.28 ---
RS-004	ASARCO Middle Outfall	1.2 (1.0-1.4) (n=2)	11/18/75-2/24/81	360 (200-760) (n=2)	3.6 (2.0-7.6)
RS-005	ASARCO South Outfall	3.4 (1.5-4.3) (n=3)	11/18/75-9/15/82	360 (34-2,300) (n=8)	10 (0.96-65)
RS-022	Tacoma North Sewage Outfall	4.8 --- (n=1)	6/30/79-9/14/81	3.0 (1.4-6) (n=3)	0.12 (0.056-0.24)

NOTE: Lead has been analyzed for but not detected in RS-040. Detection limits ranged from 2 to 20 ug/l. Lead has been detected in RS-020 (200 ug/l) and RS-070 (29-400 ug/l); however, no flow data are available from which to calculate loadings.

Table 7.7.9

ZINC: SUMMARY OF LOADINGS FROM DISCHARGES ALONG THE RUSTON SHORELINE

Drain #	Drain Name	Flow (MGD) (Avg. and Range) (# of Observations)	Period of Observations for Contaminant Concentrations	Concentration (ug/l) (Avg. and Range) (# of Observations)	Loading (lbs/day) (Avg. and Range)
RS-003	ASARCO North Outfall	0.48 (0.32-0.63) (n=2)	11/18/75-9/15/82	49 (10-160) (n=4)	0.20 (0.04-0.64)
RS-004	ASARCO Middle Outfall	1.2 (1.0-1.4) (n=2)	11/18/75-9/15/82	2,600 (2,000-4,500) (n=4)	26 (20-45)
RS-005	ASARCO South Outfall	3.4 (1.5-4.3) (n=3)	11/18/75-9/15/82	3,400 (430-14,000) (n=7)	96 (12-400)
RS-022	Tacoma North Sewage Outfall	4.8 --- (n=1)	6/30/79-4/28/82	150 (20-380) (n=4)	6.0 (0.80-15)
RS-040	48-inch Concrete Pipe	0.91 (0.64-1.2) (n=2)	9/14/81-4/28/82	39 (20-57) (n=2)	0.30 (0.15-0.43)

NOTE: Zinc has been detected in RS-020 (60 ug/l) and in RS-070 (50-430 ug/l); however, no flow data are available from which to calculate loadings.

and then sent to the arsenic recovery plant where it was volatilized, settled, and condensed. The production of elemental arsenic and arsenic trioxide occurred separately. Arsenic trioxide was heated and recondensed in elemental form as a solid and shipped out (U.S. EPA 1983b).

Copper ore arrived at the plant by ship. Off-loading occurred at the southern dock. Ore was crushed either prior to shipment or at the plant. It was stored for smelting in the fine ore building. Most waste materials and sludges generated in process were also put into the fine ore building and eventually resmelted.

Specific historical practices that have contributed most heavily to the observed contaminants in Commencement Bay cannot be determined because of the age of the facility and the relatively short (i.e., 20-yr) history of regulated emissions and discharges. The main stack and the main smelting operations date back to the turn of the century. The refinery buildings were added in the early 1920s and the sulfur dioxide plant was added in the mid-1970s. WDOE inspections have consistently failed to trace drainage lines from various buildings to their ultimate discharge point. Dye testing has been tried numerous times and consultations with plant managers and employees have had limited success.

As discussed in Section 7.7.3, most metals of concern (except mercury and nickel) have been measured in ASARCO discharges. Although the effluent has not been analyzed for organic compounds of concern, at least some of them could be associated with spills from the ASARCO facility. Each contaminant of concern is discussed below with regard to its known or potential presence in ASARCO effluent, atmospheric emissions, surface runoff, or groundwater.

Metals (Arsenic, Copper, Cadmium, Lead, Mercury, Zinc)--Numerous sources of metals at the ASARCO facility could have released pollutants along the Ruston-Pt. Defiance Shoreline. Among them are the three NPDES-permitted ASARCO outfalls, which discharge 8.4 MGD of site runoff and noncontact cooling water to Commencement Bay. Prior to 1976, when discharge of contact cooling water ceased, contact and noncontact cooling waters were mixed and discharged through the outfalls (Springer 1975). The ASARCO outfalls also discharge stormwater runoff, which is contaminated with metals from stack fallout and from fugitive dust emissions from the various process buildings (U.S. EPA 1983b; Springer 1976; Pierce, R., personal communication). The outfalls also carry runoff originating as groundwater seeps in the area of the plant stack (Hart-Crowser and Associates 1976).

Typically, the south outfall (RS-005) contains the highest concentrations of metals. The flow from this discharge is aproximately 3-4 MGD and is composed of saltwater noncontact cooling water from the acid plant, springs, surface runoff from ASARCO property, and miscellaneous freshwater input from cooling water use. This discharge enters a dispersion pond made from slag, from which the water percolates into the bay. Chronic problems of overflow and direct discharge to the bay have been noted in this area (Heffner 1981). This outfall pond is known to flood at high tide, with direct mixing and overflow.

The middle outfall (RS-004) drains the primary smelting areas, arsenic storage areas, and the copper anode pond where contact cooling waters were recirculated. It also serves as a surface stormwater runoff ditch. The flow from RS-004 is approximately 1-2 MGD.

The north outfall (RS-003), with the smallest of the three flows (approximately 1 MGD), drains the old refinery areas and the laboratory. Water from the foul water system, which drains the area of the arsenic kitchens, may be discharged indirectly through this outfall.

A 54-in city of Ruston storm drain (RS-002) located to the north of the ASARCO property discharges runoff from the oil tank storage areas and powerhouses. It is unknown if this drain serves other areas of the plant or if cross-connections exist with the north outfall system. Sampling data are not available for this drain (Pierce, R., personal communication). The drain may flow at 1-2 MGD, much of it from the ASARCO property.

ASARCO's NPDES permit established limits for flow, pH, and oil and grease. ASARCO was required to monitor metals in their discharges although no limits were established. Because of the problems associated with tidal flooding, particularly in the south outfall, these data may not be accurate. However, the discharges generally improved with time as the company installed recirculation devices and as smelting production decreased (Pierce, R., personal communication). With shutdown of smelting activities in March, 1985, the only remaining discharge from the outfalls is runoff and cooling water from the foul water system.

Metals may migrate from the facility via groundwater. In January and March, 1985, WDOE collected groundwater samples from wells on ASARCO property. Metals analyses indicated that concentrations of arsenic, cadmium, and lead were above the maximum contaminant levels as defined by National Interim Primary Drinking Water Regulations. Concentrations of organic contaminants were at acceptable levels.

The metals in groundwater may have originated from ASARCO slag. Most of the plant property west of Ruston Way is composed of slag. In the early years of the plant's history, molten slag was dumped directly into seawater. Later, dikes were constructed and molten slag was dumped behind them. Many of the plant's facilities now stand on land created by these activities. Although slag depth has not been measured, it is known to extend 10-12 m below sea level at the seaward edge of the property (Cloud 1979). Portions of the slag are known to have cracks and gas pockets, allowing water to move through these materials (Cloud 1979). Although no data are available regarding groundwater contamination on the ASARCO property, release of metals via this route could be significant, particularly because of the tidally induced flushing of the slag fill. In addition, there have been chronic, low-volume discharges of acidic wastewaters (pH 1-2) to the ground as recently as 1982 (Pierce and Anderson 1982a). Acidic conditions would promote leaching of metals from the slag.

Another major route for release of metals is air emissions from the main stack at ASARCO and from dust process emissions. In a permit granted by the Puget Sound Air Pollution Control Agency (PSAPCA), limitations were established for total particulates, sulfur oxides, and arsenic emissions. In addition, the facility was required to monitor and report lead and mercury emissions to PSAPCA on a monthly basis (Anderson, J., personal communication). Process emissions declined with production declines. There has been little or no decrease in emissions due to installation of new process controls in the last few years (Anderson, J., personal communication). Direct dust fallout from the stack and fugitive emissions from the plant property have not been studied well. It has been estimated (U.S. EPA 1983b) that about 34 lb/h of arsenic may be released via fugitive arsenic process dust emissions, with most of the arsenic coming from process of gases in the converter operation of the plant.

Crecelius et al. (1975) indicated that the arsenic-to-antimony ratio in ASARCO smelter stack dust is about 10 to 1, while the ratio in slag is about 1 to 1. Sediments collected in the vicinity of ASARCO and throughout the nearshore/tideflats area during the Superfund project typically showed arsenic-to-antimony ratios well in excess of 20 to 1, making it impossible to discriminate contamination by atmospheric sources from that of other sources using this technique.

Metals are released to Commencement Bay from the ASARCO facility via atmospheric emissions, outfall discharges, surface water runoff, and groundwater. Available data are inadequate to establish which of these routes has been the greatest contributor to the observed contamination. Changes in metal input as a result of the plant's closure cannot be determined at this time. Because soils on plant property are contaminated, discharge of metals via runoff will continue. Release of contaminants via groundwater will also continue.

Polycyclic Aromatic Hydrocarbons--Heavy residual fuel oils, such as Bunker C, are used at the ASARCO facility to fuel the furnaces, roasters, and converters. The bunker oils are brought in by ship, off-loaded at the north dock, and stored in large tanks on the north end of the property. These tanks are bermed, but the bottom of the storage area is not sealed. A 1982 inspection by WDOE noted oil within the diked area (Pierce and Anderson 1982b). Spills of Bunker C oil from all three outfalls have been reported in WDOE files, and past spills have coated the slage trench of the middle outfall with Bunker C oil (Randt 1976). Spills have also occurred during off-loading of tankers and transfer of oils to bulk storage tanks.

Another source of HPAH to this area of Commencement Bay is combustion of Bunker C oil and subsequent release via stack emissions. Fluoranthene/indeno(c,d)pyrene ratios (f/i) at Stations RS-17 and RS-03 are high (38 to >150), possibly indicating a specific combustion source such as ore smelting (see Section 7.2.3.3). However, the lack of a consistently high f/i ratio at all stations around ASARCO suggests that smelting combustion products are not the sole source of HPAH.

Lighter fuels, such as gasoline and diesel, are used in small equipment pumps and vehicles at various places on the property. Light fuels are stored near the central dock. According to ASARCO's July, 1983 SPCC plan, three gasoline tanks and one diesel tank are buried underground. Other light fuel storage tanks are present on the property above ground. An oil pumping station is located in the central dock area, as well. An oil/water separator was installed along the middle outfall line in the late 1970s.

Lighter fuels have spilled to the ground and drained to each of the outfalls over the years. ASARCO's NPDES permit allows no more than 15 mg/L of oil and grease and no visible sheen. A number of WDOE inspections have noted sheen in the outfalls and oil stains on the ground. Samples from Station RS-18, off the middle outfall (RS-004), showed the highest surficial sediment contamination of both LPAH and HPAH on a dry-weight basis. This is consistent with known spillage of fuels in the central portion of the plant, which would eventually reach the middle outfall and nearby bay sediments. HPAH concentrations were also elevated off the north outfall and north dock, consistent with spillage of Bunker C oil during off-loading.

PCBs--There are at least three potential PCB sources on the ASARCO property: two powerhouses and a utility substation. The Cottrell powerhouse supplies power to large electrostatic precipitators used in final processing of copper, arsenic, and sulfur oxides. Additional transformers are located north of this powerhouse in the drainage area served by RS-002. As of 1982, the company was slowly changing to non-PCB-containing transformers. A WDOE inspection on May 11, 1982 (Pierce and Anderson 1982b) noted the presence of oil stains on the floors in the Cottrell powerhouse. If spills were to occur from this powerhouse, it is likely (although not proven) that liquids would drain to the anode pond and subsequently through the middle outfall (RS-004).

A second Cottrell powerhouse, located on the southwestern portion of the property which supplies power to the liquid sulfur dioxide facility. This facility was completed in 1974 (ASARCO undated). PCB concentrations in existing and past transformers in this powerhouse, if any, are not known. Spills from this facility would drain into the bay through the south outfall (RS-005).

A Tacoma City Light substation is located at the northern end of the plant property. It is unknown whether this substation contains any transformers with PCB oils, but it is likely that this was the case historically. Spills from this facility would drain to the north outfall (RS-003) or to the 60-in city of Tacoma storm drain (RS-002), and subsequently to Commencement Bay.

Sediment core data do not reveal whether PCB contamination is historical or ongoing, since the vertical pattern of contamination is different in each core. Recent contaminant input appeared greater than historical input in only one core (Station RS-61 off the north outfall). It is unknown whether any of the transformers on the ASARCO property or at the Tacoma City Light substation still contain PCB oils. The ultimate disposition of the ASARCO transformers if and when the facility closes entirely is also unknown.

7.7.4.2 Ruston-Pt. Defiance Shoreline Segment 1 - Station RS-13--

Samples from Station RS-13 in Segment 1 were found to contain aromatic hydrocarbons, dibenzofuran, 2-methylphenol, and 1,4-dichlorobenzene concentrations that were 1.4-5.5 times greater (dry-weight basis) than those at other stations in Segment 1. This would suggest the presence of at least one source in the vicinity of Station RS-13.

A breakdown product of lignin, 2-methylphenol is commonly found in pulp mill effluents. The chlorination of monochlorobenzene produces 1,4-dichlorobenzene, which is used as an insecticide and air deodorant (U.S. EPA 1980c). The PAH are components of petroleum products and thus are ubiquitous in a heavily developed area such as Tacoma.

The Ruston-Pt. Defiance Shoreline in the vicinity of Station RS-13 is occupied by several fish markets and restaurants (e.g., Johnny's Ocean Fish, Carrs Landing, Charlie's Fish Bar). None of these establishments is likely to be major sources of these compounds. However, an industry no longer in the area may have been the source. The only industries known to have occupied the area are the Tacoma Mill, which operated from 1892 through about 1920, Tacoma Boatbuilding, and Aero Jet. No other information is available on historical industries in the area, and there are no sediment core samples that would permit an assessment of historical patterns of contaminant input.

An alternative source for the contamination observed in samples from Station RS-13 is the city storm sewer system. Rogers et al. (1983) reported two major discharges in the vicinity of Station RS-13: a 60-in concrete pipe (RS-039) and a 48-in concrete pipe (RS-040), both located about 150 m west of Station RS-13. The RS-039 outfall is no longer used; all effluent is diverted to RS-040. The drainage area served by RS-039/040 is approximately 500 ha in size and includes the University of Puget Sound and a residential/light commercial area of Tacoma.

The RS-040 outfall does not appear to be a likely ongoing source for the contamination observed at Station RS-13 for several reasons. First, 2-methylphenol and 1,4-dichlorobenzene would not be expected in a typical effluent originating as runoff from a residential area. Second, the RS-040 effluent has been analyzed on two occasions for these compounds, and detectable concentrations were not reported (see Section 7.7.3). Finally, drain RS-029 serves an adjacent area of comparable size to that served by RS-040. Although both drainage areas are of similar composition (principally residential, with some small commercial establishments) only sediments in the vicinity of the RS-040 outfall showed elevated concentrations of aromatic hydrocarbons, 2-methylphenol, and 1,4-dichlorobenzene. Comparable contamination was not observed at Stations RS-14 and RS-02 near the RS-029 outfall.

Drains RS-039/040 may have been a source of the contaminants of concern in the past. Prior to the early 1960s, the RS-039 outfall discharged domestic sanitary sewage as well as runoff. The compounds of concern may have been introduced to the bay at that time and are now present in surficial sediments as a result of recent sediment disturbance. However, there have been no dredging activities in this area in recent years.

7.7.5 Summary and Recommendations

No sources can be definitively identified for the contaminants of concern at Station RS-13 in Segment 1. The spatial distributions of the inorganic contaminants of concern generally showed little evidence of a major source within this segment. Metals concentrations in samples from Station RS-13 were typically two orders of magnitude less than those in neighboring Segment 2. Neither nearby properties nor drains appear to be likely ongoing sources for the organic contaminants present in samples from Station RS-13. However, it is possible that historical industries or past discharges (pre-1960 to 1962) from drain RS-039 were the source of the contaminants. Further attempts at source identification would require additional sampling to confirm the contamination now evident only on the basis of a single sample; to determine if there is a spatial gradient of contamination to help identify the source(s); and to determine whether contamination is ongoing, recent, or historical.

Sediment contamination in Segment 2 can be attributed to the ASARCO property, with the possible exception of PCBs. The firm is a documented major source of metals, with the plant's three NPDES-permitted outfalls alone contributing 780 lb/day of metals to Commencement Bay. Many documented releases of fuels have contributed to the PAH contamination now observed in sediments of the Ruston-Pt. Defiance Shoreline. Transformers containing PCBs have been used on the ASARCO property. While there have been no documented spills from these transformers, the spatial gradient of PCB contamination in the bay sediments suggests that releases have occurred. Tacoma City Light maintains an electrical substation near the ASARCO property. Past spills from this facility could also be responsible for the observed contamination of bay sediments, particularly near the ASARCO north outfall.

Although ASARCO is the major source of contaminants in Segment 2, for most of the contaminants it is not possible to conclude that the major input has occurred through single route. Contaminants may migrate from the ASARCO property into the bay through several routes:

- Outfalls - Four outfalls serve the ASARCO property, three of which are NPDES-permitted. Their effluents originate from a variety of sources, including stormwater runoff, groundwater seepage, noncontact cooling water, contact cooling water (pre-1976), and spills. The three discharges have been sampled are major sources of metals. These outfalls have also carried spilled petroleum products to the bay, contributing to the PAH contamination. The high PCB concentrations (>500 ug/kg) along the ASARCO shoreline suggest that spills in any or all of three transformer yards have entered the bay through these outfalls.

- Groundwater - Much of the ASARCO property has been created by the dumping of molten slag into Commencement Bay. Movement of groundwater through this slag, promoted by tidal action, may be a significant source of metals to the bay. Chronic discharges of acidic wastewater may have enhanced leaching of metals from the slag. The historical practice of spreading molten slag on the ground surface and irrigating it to promote cooling may also have contributed to metals contamination via groundwater.

- Atmospheric Emissions - Atmospheric deposition from the stack emissions may contribute to stormwater runoff and/or groundwater contamination.

A decrease in contaminant release can be expected with the recent closure of the copper smelting operations at ASARCO, particularly in atmospheric emissions. However, groundwater and discharge of storm water and/or cooling water through the four outfalls can be expected to continue introducing contaminants to the bay for many years to come.

A comprehensive air, water, and sediment quality monitoring program is recommended to determine the effect of reduction in plant operations on contaminant release and appropriate remedial actions. This investigation should include components to assess fugitive dust emissions, soil quality, geohydrology, outfall effluent characterization, and receiving environment quality. Until this investigation is complete, it will be impossible to determine appropriate source control activities and their effectiveness in reducing contamination in Bay.

8. RECOMMENDATIONS OF AREAS AND SOURCES FOR POTENTIAL REMEDIAL ACTIONS

8.1 INTRODUCTION

The final prioritization of problem areas for potential remedial actions is presented in this section. Recommendations of areas and sources for these remedial actions are based on evaluations of:

- The environmental hazard indicated by the problem area contamination, toxicity, and biological effects
- The spatial extent of each problem area
- The confidence that sources of potential problem chemicals in each problem area have been identified.

A prioritization of problem areas and problem chemicals was made in Section 6. Eight problem areas were given a high priority for source evaluation, four problem areas were given a second priority for evaluation, and nine problem areas were not included for priority source evaluation. The spatial extent of each problem area was also defined in Section 6, but was not considered in the development of recommendations of problem areas for source identification. In this section, the relative spatial extent of each problem area is considered, along with the magnitude of contamination, toxicity, and biological effects. For example, large areas with a high degree of environmental hazard are ranked higher than isolated hot spots posing a similar hazard. Source evaluations for each problem area are also rated according to the level of confidence that the problem sources have been identified. Thus, the highest ranking problem area for potential remedial action is large, poses a substantial environmental hazard, and has well-characterized sources. In this ranking method, a small "hot spot" exhibiting substantial effects that have been traced confidently to a contaminant source may be ranked at the same, or even higher, priority than a much larger problem area with unknown sources. To allocate resources efficiently, "hot spots" with known sources would be recommended for potential remedial action before the larger area with unknown sources.

Potential remedial actions include source control and/or sediment remedial action (see Tetra Tech 1984a). The feasibility of such actions is considered in a separate report for Task 6 of the Commencement Bay Superfund Remedial Investigation.

A final prioritization of Commencement Bay problem areas is presented in Table 8.1. Scores for each problem area in three categories (environmental significance, spatial extent, and confidence of source identification) were summed to estimate the relative priority for potential remedial action. Environmental significance was scored from 1 to 4 according to the magnitude of observed contamination, toxicity, and biological effects. The eight highest-priority areas identified in Section 6.4 were given a score of 4

TABLE 8.1 FINAL RANKING OF PROBLEM AREAS

Segment Containing Problem Area[a]	Environmental Significance	Spatial Extent	Confidence of Source Identification	Total Score
RSS2	4	4	4	12
SPS1	4	3	4	11
CIS1	4	3	4	11
HYS5	4	3	4	11
SIS1	4	4	3	11
HYS1	4	4	3	11
HYS2	4	2	4	10
CIS2	4	1	3	8
MDS1	3	3	2	8
RSS3	1	3	4	8
CIS3	3	2	2	7
				b
HYS4	3	2	1	6
RSS1a (RS-13)	3	1	1	5
BLS2	2	1	1	4
MIS1	2	1	1	4
RSS1b (RS-15)	1	1	1	3
HYS3	1	1	1	3
BLS1	1	1	1	3
HYS6	1	1	1	3
BLS3	1	1	1	3
BLS4	1	1	1	3

[a] Problem areas did not always encompass an entire segment. Problem areas in the segments indicated are listed in order of their total score for environmental significance, spatial extent, and confidence of source identification.

[b] Identification of potential remedial technologies was conducted for problem areas with a total score greater than or equal to 7.

for environmental significance. The four second-priority sites (Section 6.4) were given a score of 3, and the two third-priority sites (plus Milwaukee Waterway) were given a score of 2. All remaining lower-priority problem areas were given scores of 1.

The spatial extent (surface sediments only) of each problem area was estimated by planimetry. Problem area boundaries were established by the location of current and historical stations where chemical concentrations exceeded AET. Historical stations for which only amphipod bioassay data were available were also used to set problem area boundaries when high toxicity (>50 percent mortality) was indicated. No interpolation of chemical concentrations was attempted between stations because of the often patchy distribution of problem sediments. However, when no data were available for nearshore subtidal and intertidal sediments, the problem areas were assumed to extend to the shore. Scores were assigned on the basis of size of each problem area as follows:

- >50 acres score = 4
- 30-50 acres score = 3
- 10-30 acres score = 2
- <10 acres score = 1.

The confidence of source identification was scored according to the following qualitative criteria:

- Ongoing sources were well-identified by spatial patterns of contamination (and effects), and by chemical characteristics that matched those of the receiving water environment; score=4. Or, contamination was clearly established as historical, although sources may not have been well-identified; score=4
- Potential sources were identified, but their relative contributions compared with historical deposits were not clear; score=3
- Adjacent sources were suggested by land use or drainage patterns, but spatial patterns of contamination were ambiguous; score=2
- Source unidentified; score=1.

All problem areas with clearly identified sources (i.e., score=4) exhibited major environmental effects. The exception was the problem area within Segment RSS3 on the Ruston-Pt. Defiance Shoreline, where the source of metals contamination is believed to be ASARCO slag or ores in the sediments. No benthic data directly comparable to those in other areas (i.e., 0.06-m2 grab) were collected from this problem area because of sampling difficulties. However, qualitative evaluation of replicate 0.1-m^2 grab samples indicated a general similarity to Carr Inlet reference conditions. The differences in numbers of species and abundances of the major taxonomic groups were not large, and probably reflected natural differences in benthic community structure between the Segment RSS3 site and Carr Inlet. Therefore, major impacts to benthic communities did not appear to be occurring in the potential problem area. Based on this qualitative analysis, the score for environmental significance was reduced from 2 to 1 (Table 8.1). This problem area is still recommended for evaluation of potential remedial action.

All problem areas in Table 8.1 with a total score <6 have a low priority for evaluation of potential remedial action. These latter problem areas had largely unidentified sources and were not extensive. Potential hot spots in Segments HYS4 (Hylebos Waterway) and RSS1 (Station RS-13; Ruston-Pt. Defiance Shoreline) are included in this group. Ship scour or some unidentified dredging activity could have resulted in the multiple significant benthic depressions observed at a single station (HY-37) in the Segment HYS4 hot spot. Further characterization of potential sources is required for the Station RS-13 hot spot within Segment RSS1. Further source identification of problem chemicals summarized in Table 6.14 (see Section 6.5) is recommended for each of these low priority problem areas before the feasibility of any potential remedial action is evaluated.

Recommendations for the remaining problem areas with scores >7 in Table 8.1 are presented below.

8.2 RECOMMENDATIONS FOR POTENTIAL REMEDIAL ACTION

Potential remedial actions include source control and sediment actions such as removal, capping, or in situ treatment. All problem areas discussed below have ongoing, potentially ongoing, or unknown sources of problem chemicals. Remedial actions with respect to the contaminated sediments is recommended for all areas only after the sources have been identified and effectively controlled.

8.2.1 Hylebos Waterway

Hylebos Problem Area 1 (in Segment HYS1)--

Potential sources of HPAH, arsenic, copper, lead, and zinc were identified for the problem area in Segment HYS1 of Hylebos Waterway. Source control measures are recommended to reduce HPAH discharge from Kaiser Ditch. Source control evaluation is also recommended to reduce metals discharge (especially arsenic and zinc) from unpaved log sort-yards (Wasser Winter, Cascade Timber yard #2, Dunlap Towing, Louisiana Pacific), and from Hylebos Creek (B&L Landfill and Fife Ditch).

Hylebos Problem Area 2 (in Segment HYS2)--

PCBs were the highest priority chemicals found in the problem area defined within Hylebos Segment HYS2. Exposure of historical accumulations of PCBs (and other chemicals, i.e., HCBD) by dredging was identified as the most probable source of this contamination. There was little evidence of an ongoing source of PCBs in this area. A PCB source reconnaissance is recommended prior to evaluation of sediment remedial action. Potential source control must also be evaluated for other problem chemicals discussed below that have significant ongoing sources in this problem area. The extent of subsurface PCB contamination was not well-characterized, but likely extends over a broad area. This problem should be considered when planning dredging projects in Hylebos Waterway.

Elevated HPAH concentrations were found in subtidal sediments of the problem area in Segment HYS2 near the boundary between Segments HYS1 and HYS2. These sediments do not appear to be within the dredged area discussed for PCBs. The HPAH contamination is likely an extension of the contamination found in the problem area within Segment HYS1. As discussed previously, source control evaluation for HPAH has been recommended for the Kaiser Ditch, the major HPAH source to Hylebos Waterway.

Pennwalt Chemical Corporation was identified as an ongoing source of chlorinated ethenes, chlorinated butadienes, arsenic, copper, lead, and zinc to intertidal sediments of the Segment HYS2 problem area. Tetrachloroethene is also elevated in some of the subtidal sediments. Source control evaluation is recommended for these chemicals in the main plant outfall, surface drains, groundwater seeps, and groundwater in shallow and intermediate aquifers.

Hylebos Problem Area 3 (in Segment HYS5)--

Source control evaluation for chlorinated compounds, including chlorinated ethenes and chlorinated butadienes, from Occidental Chemical Co. is recommended. Although chlorinated butadienes (with the exception of HCBD) did not exceed toxicity or benthic AET (Section 6), source control for these substances is still recommended for the Occidental main outfall based on their extreme concentrations in this area. Very high concentrations of chlorinated ethenes in this area were restricted to the immediate vicinity of the Occidental Chemical Co. docks. Because of the localized nature of this contamination, clear response gradients could not be established. However, because of the magnitude of chlorinated ethene contamination, these substances warrant a high priority for source control. The source of PCB contamination in this area was not established. A PCB reconnaissance in this area is recommended. PCB contamination in this area should be considered when dredging is planned.

8.2.2 Sitcum Waterway

Ore unloading operations at the Port of Tacoma docks are a potential source of metals contamination to the north shore of the waterway. Although the contribution of this source to overall sediment metals contamination cannot be established with available data, it is recommended that evaluations be conducted on possible control technologies for minimizing release of ore into the waterway.

Three storm drains are also major contributors of metals to Sitcum Waterway. Source identification within the drainage areas of these storm drains is necessary before source controls can be implemented.

8.2.3 St. Paul Waterway

The main outfall from the Champion International pulp mill located at the mouth of St. Paul Waterway, is an ongoing source of alkylated phenols (or their precursors), methoxyphenols, copper, organic enrichment, and chloroform. Source control evaluation for alkylated phenols (or their precursors) is recommended at Champion International pulp mill. Source control for copper and chloroform is also recommended because these contaminants were measured at elevated concentrations in plant effluent or, in the case of copper, exceeded applicable water quality criteria.

8.2.4 Middle Waterway

Ship repair operations were identified as potential sources of mercury and copper in Middle Waterway. No definite sources of pentachlorophenol, dichlorobenzenes, and PAH have been identified. Evaluation of source control at the ship repair operations is recommended. Source investigations for pentachlorophenol, dichlorobenzenes, and PAH are recommended before evaluating source controls.

8.2.5 City Waterway

City Problem Area 1 (in Segment CIS1)--

The south Tacoma and Nalley Valley drains at the head of City Waterway are the largest ongoing sources of metals (especially lead) and organic material. The specific sources of metals and organic matter within these drainage areas have not been identified. Therefore, source investigations are recommended within these drainage areas. Source control alternatives should be evaluated following identification of specific sources. Source investigations and source control evaluations should also be conducted for the 15th Street drain, which also contributes metals and PAH to the waterway. Source control evaluation is recommended for Martinac Shipbuilding, which is a probable source of copper and zinc to City Waterway. The wood products industries, the Tar Pits site, and the 23rd and A Street coal gasification site are possible sources of 4-methylphenol to City Waterway. The contributions of 4-methylphenol from these sources should be investigated.

City Problem Area 2 (in Segment CIS2)--

Ongoing sources of the contaminants of concern in Wheeler-Osgood Waterway could not be identified. Source investigations are therefore recommended for 4-methylphenol, 1,2-dichlorobenzene, organic material, lead, and zinc. Source investigations should include evaluation of specific sources of these contaminants within the drainage area served by CW-254. The potential for groundwater transport of 4-methylphenol from the Tar Pits site also requires further investigation.

City Problem Area 3 (in Segment CIS3)--

Sources of the problem contaminants in City Waterway Segment 3, including LPAH and HPAH, could not be identified with existing information. Therefore, remedial action for this problem area is not recommended until contaminant sources and transport mechanisms have been established. Further source investigation is recommended for PAH.

8.2.6 Ruston-Pt. Defiance Shoreline

The ASARCO facility was identified as the source of metals (including high-priority mercury and arsenic) and PAH to the adjacent problem area. Although ASARCO is the major source of contaminants to the problem area, for most of the contaminants it is difficult to determine if the major loading has occurred through any one route (i.e., process effluent, surface water runoff, groundwater). Because the facility has closed recently, a characterization and source control evaluation of the residual discharge of contaminants from site runoff and groundwater is recommended. A reconnaissance survey is recommended to determine possible sources of PCBs to this problem area.

8.3 GENERAL RECOMMENDATIONS

There were several PCB hot spots in the project area where PCBs concentrations exceeded apparent effects thresholds. In addition, general PCB contamination within the waterways is sufficient to be the apparent cause of elevated PCBs in fish muscle, fish liver, and crab muscle tissue. PCBs are the chemicals that are responsible for the highest predicted risk to human health from fish consumption. The sources of PCBs are unknown. A general reconnaissance survey of the area for PCB sources with appropriate followup where warranted is recommended. Other chemicals for which general reconnaissance surveys are recommended include aromatic hydrocarbons and dibenzofuran.

9.0 OVERVIEW OF CONTAMINATION AND BIOLOGICAL EFFECTS IN COMMENCEMENT BAY

The Commencement Bay Nearshore/Tideflats Remedial Investigation included a comprehensive assessment of sediment contamination and associated biological effects. Results of this assessment were used to identify and prioritize problem areas. An overview of these conditions in Commencement Bay is provided in this section.

During this and previous studies, several hundred chemicals have been tentatively identified in Commencement Bay sediment samples. Routine analyses have been conducted for about 150 chemical variables. Chemicals detected in over two-thirds of the surface sediments analyzed in the Superfund study included phenol, 4-methylphenol, PAH, 1,4-dichlorobenzene, PCBs, dibenzofuran, and most U.S. EPA priority pollutant metals. Most of these chemicals had already been reported in many areas of Commencement Bay. Chemicals detected only rarely or not at all in the present study included pesticides, most organonitrogen compounds, most chloro- and nitrophenols, halogenated ethers, 2,3,7,8-dibenzodioxin (never detected), selenium, and thallium. High concentrations of some of the pesticides in this group had been found in past studies, but the findings had not been confirmed by mass spectroscopy.

Sediment contamination throughout the Commencement Bay study area is variable both in concentration and composition. The highest PAH concentrations were found near the head of Hylebos Waterway. Benzo(a)pyrene was found at over 1,000 times reference conditions at one Hylebos Waterway station. In this study and in others, Hylebos Waterway sediments contained a complex mixture of chlorinated compounds, many of which were unidentified. Tri- and tetrachlorinated butadienes were found at well over 1,000 times reference conditions near the mouth of the waterway. Other chemicals measured at over 1,000 times reference concentrations were 4-methylphenol and 2-methoxyphenol (guaiacol) in sediments adjacent to the main outfall of the Champion International pulp and paper mill in St. Paul Waterway, and four metals (antimony, arsenic, copper, and mercury) in sediments adjacent to the main outfalls of the now closed ASARCO copper smelter on the Ruston-Pt. Defiance Shoreline. With some exceptions, concentrations of most chemicals measured in the current investigation of subtidal sediments were comparable to or higher than those in subtidal and intertidal sediments collected in previous studies. Chlorinated ethene concentrations in intertidal sediments from Hylebos Waterway were higher in other studies than those in subtidal sediments in the present study. Metal concentrations in sediments near drains at the head of Sitcum Waterway were also higher in other studies.

In the present study, Blair and Milwaukee Waterways contained the least contaminated subtidal sediments. Additional sampling was not conducted in the Puyallup River, but historical sediment concentrations were low. The most extreme contamination in the remaining areas was typically located in small areas near point source discharges. Pronounced gradients in chemical concentrations were observed in several waterways (e.g., Hylebos, St. Paul, and City Waterways) and along the Ruston-Pt. Defiance Shoreline. Concentrations of contaminants in sediments collected well outside of Hylebos and Blair Waterways were low, approaching reference conditions in most cases.

For most substances, the range of concentrations was greater in subsurface sediments than in surface sediments. The depth of penetration in the sediments was often limited by textural characteristics. Concentrations approaching reference area conditions for all chemicals were reached at the bottom of only some cores. Many chemicals present at elevated concentration at depth in cores were still below apparent effect thresholds for toxicity and benthic effects. Consistently low concentrations of chemicals were reached at the bottom of all cores collected in a special drilling program in Blair Waterway.

Studies of benthic macroinvertebrate assemblages and laboratory bioassays of sediments were used as site-specific indicators of biological effects and toxicity in Commencement Bay. These studies demonstrated that areas of high toxicity and effects on benthos were generally isolated near known pollutant sources. The most severe effects were observed at single sampling stations near two industrial facilities: Champion International pulp mill and the ASARCO smelter. In these areas of extreme adverse effects, very few animals lived in the sediments or survived a 10-day laboratory exposure to the sediments. These areas were also characterized by very high sediment contamination in which concentrations of several chemicals were over 1,000 times higher than reference concentrations. In these two areas, there was noticeable improvement in benthic conditions at the next closest transect stations (250-400 ft away), indicating that the areas of maximum effects were of limited spatial extent. Biological conditions varied considerably from station to station in the waterways. For example, in Hylebos Waterway, areas of high toxicity and altered benthic communities were interspersed among areas of low toxicity and benthic effects. Some waterways displayed well-defined areas of high toxicity and benthic effects (e.g., Hylebos and City Waterways) and others displayed little evidence of such effects (e.g., Milwaukee and Middle Waterways).

In general, the waterway sediments supported higher abundances of benthic macroinvertebrates than were found in Carr Inlet or along the Ruston-Pt. Defiance Shoreline. The waterway sediments supported fewer species than other areas sampled, indicating possible generalized effects from contamination, sediment disturbance, or presence of fine-grained sediments. Typical benthic assemblages in the waterways were dominated by polychaete worms and small clams. These organisms are important food items for many bottom-feeding fishes.

Demersal fish assemblages in the waterways were dominated by flatfishes such as English sole. Fish assemblages in the waterways were over twice as abundant as those in Carr Inlet. These fishes may be attracted by the abundant food resources in the waterways or by the increased habitat complexity in the harbor environment. English sole in several waterways had significantly elevated prevalences of one or more liver lesions. The highest overall lesion prevalence was measured in Middle Waterway, where 40 percent of English sole sampled had one or more serious lesions. The causes of these lesions are unknown, but the lesions are similar to those induced in laboratory animals exposed to toxic chemicals. The effects of these lesions on the fish are also unknown. In this study, however, fish with serious liver lesions did not exhibit reduced condition (as expressed by weight at a given length) when compared to fish without lesions.

Although many chemicals were highly elevated in Commencement Bay sediments, relatively few were detected in the tissues of English sole and crabs. The only metals that were accumulated above reference levels were copper in English sole and lead and mercury in crabs. PCBs were the most consistently detected organic compounds and were measured at concentrations about 10 times reference levels in Hylebos and City Waterways. In the heavily fished Pt. Defiance area, concentrations of PCBs in English sole were close to reference levels.

In summary, the Commencement Bay study area presents a mixed picture relative to contamination and biological effects. The bay is not an ecological disaster area with overall high contamination and pervasive biological effects. Commencement Bay is a complex estuarine environment in which the levels of contamination and effects vary considerably. While there are definite indications of stress to local biological communities (e.g., altered benthic assemblages, accumulation of contaminants in fish and shellfish, and liver lesions in flatfish), most of the area is characterized by high abundances of benthic organisms and demersal fishes, and the fish do not appear to be severely stressed by liver lesions or accumulations of toxic substances.

10.0 STUDY DESIGN EVALUATION AND RECOMMENDATIONS FOR FUTURE STUDIES

The Commencment Bay Nearshore/Tideflats Remedial Investigation involved the collection of extensive data and the implementation of a complex decision-making process. Because of the unique nature of the study area and the complexity of potential sources, contaminants, and biological effects, many of the investigative techniques and decision criteria were developed specifically for this project. This section provides a retrospective evaluation of the innovative study approach and presents recommendations for future studies of sediment contamination in the marine environment.

10.1 SEDIMENT CHEMISTRY

1. The addition of multiple (>50) isotopically labeled recovery standards to every sample increased confidence in the validity of detection limits for undetected target compounds. By forcing a search for each recovery standard, this recovery technique also increased the efficiency and reporting of target compounds that otherwise may have been overlooked in the complex extracts.

2. Use of a defined list of tentatively identified compounds to search for in each sample analyzed greatly improved the value of these data in spatial characterizations of contamination.

3. Low detection limits for organic compounds in the range of 5 to 50 ppb (dry weight sediment or wet weight tissue) were useful in defining conditions in the reference area, extent of problem areas, and interrelationships among chemical and biological indicators, and in estimating human health risks. Because major sample interferences were removed to attain these limits, improved precision was possible in the quantification of compounds present at high concentration.

4. Historical problems with potential misidentification of pesticides in sediments was successfully avoided by using mass spectroscopy instead of electron capture detection. This advantage outweighed the increase in detection limits by mass spectroscopy, but electron capture analyses are still recommended for tissue samples (with mass spectral confirmation of any high values) to obtain low enough detection limits for use in health risk assessments.

5. Sampling of suspended solids in the water column for toxic chemicals at two depths and at two times during the study made possible only a limited qualitative estimate of the ambient levels or apparent transport of chemicals. Even

with filtering 100 L of water, detection limits for most organic compounds other than PAH were too high to be useful. Water column studies are recommended only for metals, PAH (by GC/MS), or selected chlorinated compounds amenable to sensitive GC/ECD analysis. The organic analyses should be conducted with a minimum of 0.5 g of material.

6. PCB concentrations reported as total PCBs enabled an adequate characterization of the PCB distribution. This reporting format is recommended because PCB mixtures in the environment are rarely representative of original Aroclor components.

7. A two-phase coring program is recommended to determine the extent of contamination in historical sediments and to overcome penetration problems caused by textural characteristics of the sediments. The first phase (lower cost) should use a coring device (box, Kasten, wide-diameter gravity core) that can recover intact surface and near-surface sediments; the second phase (higher cost) should incorporate drilling techniques to recover deeper sediments if analysis of the bottom of the phase I core shows elevated contamination.

8. A sampling interval of up to 1 ft in sediment cores was adequate when the primary goal was focused on potential required dredging depths for contaminated sediments. However, the bottom 2 cm of each core should be analyzed in future studies of this type to reduce uncertainty as to whether a significant decline in concentration toward the bottom of the core was masked by compositing over large depth intervals.

9. Sampling intervals of 1-5 cm thickness should be used in sediment cores to estimate the chronology of deposition. This chronology can be critical in determining whether contamination is historical or ongoing.

10. Substantial quality assurance review and laboratory oversight were required in a study of this complexity. This review and oversight were based on an integration of analytical chemistry techniques with environmental trend analysis. Such an integration should be required in future studies and should always include a laboratory site visit before samples are processed.

10.2 BIOLOGICAL EFFECTS

1. The collection of four replicate 0.06-m^2 van Veen grab samples enabled an adequate assessment of benthic community structure in Commencement Bay. Use of a 0.06-m^2 grab is recommended for future studies because of substantial cost savings (per sample) over a standard 0.1-m^2 grab.

2. Statistical analyses of the abundances of major groups of benthic macroinvertebrates (i.e., total abundance, Poly-

chaeta, Mollusca, and Crustacea) enabled areas of toxic effects to be identified. Evaluation of community structure based on species-level identification was useful in assessing differences among areas and in identifying probable causes (e.g., toxicity vs. organic enrichment) of modified benthic assemblages.

3. Selection of an adequate reference area is critical to evaluation of effects on benthic macroinvertebrates because of the overriding influence of sediment particle size on these assemblages. If detailed information on the sediment characteristics of the study area and candidate reference sites is not available, a reconnaissance survey should be conducted to ensure that adequate reference sites are available for the range of sediment characteristics in the study area.

4. The current study design enabled detection of statistically significant differences in fish hepatic lesion prevalences at the waterway level. Therefore, the use of demersal fish histopathology as an effects variable can provide a relatively localized assessment of biological effects.

5. Fish histopathology is an important independent indicator of biological effects because it does not correlate with effects on benthic macroinvertebrates or sediment toxicity.

6. Analyses of contaminants in English sole muscle tissue enabled assessment of spatial differences in bioaccumulation on a waterway basis, and in some cases within a waterway. The site-specific co-occurrence of several compounds in sediments and fish muscle tissue indicates that these studies provide a reliable assessment of bioavailability of sediment contaminants.

7. Use of five fish tissue samples per area results in a relatively poor statistical power in detecting spatial differences in tissue contaminant levels. However, for important compounds such as PCBs, the current study design enabled detection of statistically significant elevations in tissue concentrations on a waterway basis that were <5 times the reference concentration.

8. Larger English sole (e.g., >300 mm total length) should be used for bioaccumulation studies to ensure that sufficient muscle tissue is available for full-scan priority pollutant analyses.

9. Full-scan priority pollutant analyses of fish livers are not recommended because of small sample sizes and the considerable sample processing required to reduce interferences from high lipid content. Analyses of fish livers may be useful, however, for specific substances such as PCBs or selected metals (e.g., mercury).

10. Volatile organic compounds were bioaccumulated by English sole in several areas of Commencement Bay. These compounds (especially tetrachloroethene) should be analyzed for in fish tissues if there is evidence of high sediment or water contamination.

11. The oyster larvae bioassay is not recommended for future studies of sediment contamination because of response similarity with the amphipod bioassay, confounding problems with high mortalities, and effects of low dissolved oxygen. To a lesser degree, the amphipod bioassay may also be subject to interpretive difficulties because of oxygen depletion during exposure to highly organically enriched sediments.

12. Amphipod bioassay mortalities may result from particle size effects where the sediments are >80 percent fine-grained materials (i.e., silt plus clay). In those cases, sediment chemistry data should be carefully reviewed, and the influence of particle size should be evaluated before concluding that observed mortalities are caused by toxic contamination.

13. Conducting sediment bioassays and benthic infaunal analyses at *each* sediment chemistry station would have enabled a much better determination of quantitative relationships [toxicity and benthic apparent effect thresholds (AET)].

14. Four kinds of hepatic lesions (neoplasms, preneoplasms, megalocytic hepatosis, and nuclear pleomorphism) should be used in assessing histopathology in English sole.

15. For liver histopathology studies, 60 fish per area is the *minimum* number required to obtain reasonable statistical discrimination (i.e., to detect differences in lesion prevalence of 10-15 percent) among areas.

16. English sole used for liver histopathology studies should be >225 mm total length and >3 years of age. All samples should also be age-corrected prior to statistical evaluation of spatial or temporal differences in lesion prevalence.

10.3 DECISION-MAKING APPROACH

1. The defined decision-making approach, incorporating five independent measures of contamination, toxicity, and biological effects (i.e., sediment chemistry, sediment bioassays, benthic macroinvertebrates, fish bioaccumulation, and fish liver histopathology), enabled an objective and defensible identification and prioritization of problem areas associated with toxic chemical contamination. For this purpose, the latter two measures were used only as average values at the waterway level. The first three measures were also used as site-specific indicators to define the spatial extent of problems areas. The use of this assessment approach ("pentad approach") is recommended in other studies of sediment contamination.

2. Using toxicity and benthic AET, the extent of problem areas could be defined and potential problem chemicals at each site could be identified. Although AET are first approximations and not proof of cause-effect relationships, the AET provide empirical evidence that helps define and narrow the "gray zone" between a clear no-effects level and an apparent effect level for different chemicals. Identifying chemicals above AET values allowed source identification efforts to focus on those problem chemicals.

10.4 SOURCE IDENTIFICATION

1. Normalization of chemical concentrations to organic carbon or percent fine-grained material was sometimes useful in giving additional source information not conveyed by dry-weight concentrations in sediments. At the most severely contaminated sites, however, gradients in dry-weight concentrations were sufficient to indicate potential sources. Normalization of chemical concentrations enabled a better definition of groups of chemicals with similar environmental distributions and potentially similar sources. Because organic carbon and grain size probably affect the bioavailability of chemicals, the continued evaluation of normalized data in developing quantitative relationships is also recommended.

2. Contaminant loading data were limited for most potential sources, and for many others, no loading data existed. This data gap impaired source evaluation and allowed prioritization of potential sources on a relative basis only. Collection of additional source data is recommended in all problem areas. These data should cover at least critical problem chemicals, with detection limits that reflect representative flow conditions and suspended solid loadings from each source (i.e., consider the detection limits of the resulting loading for each chemical). Additional measurements of flow rates are needed to establish reliable estimates of the relative magnitude of sources.

   Estimates of historical contaminant loadings are even more uncertain than those for ongoing sources. Contaminant loadings in a problem area may have changed over time because different industries occupied the site or because changes in industrial activities altered the contaminant loadings in the discharges. Therefore, additional review of historical industrial and land use practices are recommended, with a focus on the problem chemicals and products that contain these chemicals.

3. In several of the problem areas it was difficult, or impossible, to determine whether the contamination observed in the sediments was from historical or ongoing sources. Data gaps that prevented this determination included inadequate or missing source loading data for the problem chemicals, and inadequate sedimentation rate estimates for the individual waterways.

Additionally, disturbance from dredging activities within the problem areas complicated the assessment of relative depositional periods of the problem chemicals. This was the case for PCBs in Hylebos Waterway Segment 2. Source investigations have revealed little about whether PCBs are from historical or ongoing sources.

4. Sediment accumulation rates in major problem areas in waterways such as City and Hylebos obviously differ substantially from one another, but are needed to address remedial alternatives. Representative rates are unknown. While conditions in these waterways present problems in applying dating techniques, dating of selected cores (e.g., by the Pb-210 technique) is recommended to determine if gross estimates of sediment accumulation rates ($mg \cdot kg^{-1} \cdot yr^{-1}$) may be possible in these areas.

11.0 REFERENCES

American Public Health Association (APHA), AWWA, and WPCF. 1981. Standard methods for the examination of water and wastewater. American Public Health Association, Washington, DC. 15th Edition. 1134 pp.

Anderson, J. Personal Communication (contact by JRB Associates staff, Bellevue, WA). Puget Sound Air Pollution Control Agency, Seattle, WA.

ASARCO. 1971. NPDES permit application to State of Washington. ASARCO, Tacoma, WA.

ASARCO. 1983. Water pollution spill prevention control and counter-measure plan. ASARCO, Tacoma, WA.

ASARCO. No date. Tacoma copper smelter and refinery. ASARCO, Tacoma, WA.

ASTM. 1983. Annual book of ASTM standards. Volume 11:04. Section II. Water and environmental technology. Philadelphia, PA. pp. 246-262.

AWARE, Inc. 1981. Hydrogeologic and engineering evaluations of waste management facilities for Pennwalt Corporation, Tacoma, Washington. AWARE, Inc., Nashville, TN. 300 pp.

Barrick, R.C. 1982. Flux of aliphatic and polycyclic aromatic hydrocarbons to central Puget Sound from Seattle (West Point) primary sewage effluent. Environ. Sci. Technol. 16:682-692.
BARR003F

Barrick, R.C. 12 March 1985. Personal Communication (comments to a draft report submitted by JRB Associates, Bellevue, WA; comments sent under cover letter from Dr. Thomas C. Ginn). Tetra Tech, Inc., Bellevue, WA.

Barrick, R.C., and F.G. Prahl. (In preparation). Sources and fates of polynuclear aromatic hydrocarbons in Puget Sound sediments. For submission to Estuarine Coastal Shelf Sci.

Barrick, R.C., E.T. Furlong, and R. Carpenter. 1984. Hydrocarbon and azaarene markers of coaltransport to aquatic sediments. Environ. Sci. Technol. 18:846-854.

Battelle Northwest. 1983. Tables: responses of the amphipod Rhepoxynius abronius tc sediments from locations in Puget Sound. (Unpublished report). U.S. Environmental Protection Agency Region 10, Seattle, WA. 27 pp.
BNWS002D

Battelle Northwest. 1985. Detailed chemical and biological analysis of selected sediments from Puget Sound Draft Final Report. Prepared for U.S. EPA. Battelle Northwest, Sequim, WA.
BNWS009D

Becker, D.S. (unpublished). Data collected in 1980 in support of research for Ph.D. from the University of Washington, Seattle, WA.

Becker, D.S. 1984. Resource partitioning by small-mouthed flatfishes (Pleuronectidae) in Puget Sound, Washington. Ph.D. Thesis (in review). University of Washington School of Fisheries, Seattle, WA. 150 pp.
BECK003D

Bellan-Santini, D. 1980. Relationship between populations of amphipods and pollution. Mar. Pollut. Bull. 11:224-227.
BELL101F

Boesch, D.F. 1977. Application of numerical classification in ecological investigations of water pollution. EPA-600/3-77-033. U.S. EPA Environmental Research Laboratory, Corvallis, OR. 125 pp.
BOES001F

Boys, P.A., and J.C. Sceva. 1979. Internal memorandum dated July 3, 1979 from the Region X Surveillance and Analysis Inspection Team to Gary O'Neal, Director, Surveillance and Analysis Division, U.S. Environmental Protection Agency.

Brandt, C. Personal Communication (contact by JRB Associates staff, Bellevue, WA). Retired from Hygrade Foods, Tacoma, WA.

Brown and Caldwell, and E.V.S. Consultants. 1983. Site safety plan, Tasks 3 and 4. Commencement Bay Nearshore/Tideflats Cooperative Agreement. Brown and Caldwell, and E.V.S. Consultants, Seattle, WA. 32 pp.

Brown and Caldwell, and E.V.S. Consultants. 1984. Quality assurance project plan for Commencement Bay Nearshore/Tideflats Remedial Investigation, Task 3. Prepared for Washington State Department of Ecology, Olympia, WA. Brown and Caldwell, and E.V.S. Consultants, Seattle, WA. 59 pp.

Burkhalter, R. Personal Communication (contact by JRB Associates staff, Bellevue, WA). Washington Department of Ecology, Olympia, WA.

Burt, J. Personal Communication (contact by JRB Associates staff, Bellevue, WA). Division of Industrial Safety and Health, Washington Department of Industry, Olympia, WA.

Candler, G.C. 1982a. Internal memorandum dated February 4, 1982 from C.G. Candler to D.J. Beardsley, Hooker Chemicals and Plastics Corporation.

Candler, G.C. 1982b. Internal memorandum dated December 16, 1982 from C.G. Candler to D.J. Beardsley, Hooker Chemicals and Plastics Corporation.

Can Test Laboratories. 1979. U.S. Environmental Protection Agency priority pollutant analysis of influent and effluent samples for Hooker Chemicals and Plastics Corp., Tacoma, Washington. Can Test Laboratories, Ltd., Vancouver, BC, Canada. 22 pp.

Cardwell, R.D., S. Olsen, M.I. Carr, and E.W. Sanborn. 1979. Causes of oyster larvae mortality in South Puget Sound. NOAA Technical Memorandum ERL MESA-39. U.S. Department of Commerce. Washington, DC. 75 pp.

Carpenter, R., M.L. Peterson, and J.T. Bennett. 1985. ^{210}Pb-derived sediment accumulation and mixing rates for the greater Puget Sound region. Mar. Geol. 64:291-312.

Carriker, M.R., J.W. Anderson, W.P. Davis, D.R. Franz, G.F. Mayer, J.B. Pearce, T.K. Sawyer, J.H. Tietjen, J.F. Timoney, and D.R. Young. 1982. Effects of pollutants on benthos. pp. 3-21. In: Ecological Stress and the New York Bight: Science and Management. G.F. Mayer (ed). Estuarine Research Federation, Columbia, SC.
CARR001F

CH2M HILL. 1983. Water management study. Prepared for Kaiser Aluminum and Chemical Corporation.

Chapman, P.M., and R. Fink. 1983. Additional marine sediment toxicity tests in connection with toxicant pretreatment planning studies, METRO Seattle. E.V.S. Consultants, Vancouver, BC, Canada. 28 pp.
CHAP012F

Chapman, P.M., and R.P. Fink. 1984. Effects of Puget Sound sediments and their elutriates on the life cycle of Capitella capitata. Bull. Environ. Contam. Toxicol. 33:451-459.

Chapman, P.M., and E.R. Long. 1983. The use of bioassays as a part of a comprehensive approach to marine pollution assessment. Mar. Pollut. Bull. 14:81-84.

Chapman, P.M., and J.D. Morgan. 1983. Sediment bioassays with oyster larvae. Bull. Environm. Contam. Toxicol. 31:438-444.

Chapman, P.M., M.A. Farrell, R.M. Kocan, and M. Landolt. 1982a. Marine sediment toxicity tests in connection with toxicant pretreatment planning studies, METRO Seattle. E.V.S. Consultants, Vancouver, BC, Canada. 15 pp.
CHAP010F

Chapman, P.M., G.A. Vigers, and M.A. Farrell. 1982b. Survey of biological effects of toxicants upon Puget Sound biota. I:Broad scale toxicity survey. NOAA Technical Memorandum OMPA-25. 98 pp.
CHAP001F

Chapman, P.M., D.R. Munday, and J. Morgan. 1983. Survey of biological effects of toxicants upon Puget Sound Biota. II: Tests of reproduction and impairment, plus Appendices A-E. National Oceanic and Atmospheric Administration, Washington, DC. 58 pp.
CHAP002F

Chapman, P.M., R.N. Dexter, J.D. Morgan, R.P.Fink, D.G. Mitchell, R.M. Kocan, and M. Landolt. 1984. Survey of biological effects of toxicants upon Puget Sound biota. III: Tests in Everett Harbor, Samish, and Bellingham Bays. NOAA Technical Memorandum NOS OMS 2. National Oceanic and Atmospheric Administration, Rockville, MD. 48 pp.
CHAP008F

Chui et al. 1981. (not seen; as cited by Galvin and Moore 1982).

Cloud, G. 1979. Internal memorandum dated April 19, 1979 from G. Cloud to R. Pierce (WDOE) regarding ASARCO Class II Survey.

Comiskey, C.A., T.A. Farmer, and C.C. Brandt. 1984. Dynamics and biological impacts of toxicants in the main basin of Puget Sound and Lake Washington. Vol. IIA . Report prepared for the Municipality of METRO Seattle by Science Applications, Inc.

Conestoga-Rovers, and Associates. 1984a. Tacoma plant site: evaluation of monitoring data. Occidental Chemical Corporation, Tacoma, WA.

Conestoga-Rovers, and Associates. 1984b. Tacoma off-plant disposal site investigation. Marine View Drive. Occidental Chemical Corporation, Tacoma, WA. 9 pp.

Conestoga-Rovers, and Associates. 1984c. Tacoma off-plant disposal site investigtion. Bonneville Power Authority. Occidental Chemical Corporation, Tacoma, WA. 4 pp.

Cook, K., and D. Anderson. 1983. Inspection report - North Pacific Plywood. WDOE, July 14, 1983.

Crecelius, E.A. 1983. History of contamination of sediments in Commencement Bay, Tacoma, WA. NOAA Technical Memorandum OMPA. NOAA Marine Ecosystem Analysis Program, Seattle, WA. 57 pp.

Crecelius, E.A., and N.S. Bloom. (In review). Temporal trends of contamination of Puget Sound. Submitted to the Fifth International Ocean Disposal Symposium, Proceedings.

Crecelius, E.A., M.H. Bothner, and R. Carpenter. 1975. Geochemistry of arsenic, antimony, mercury, and related elements in sediments of Puget Sound. Environ. Sci. Technol. 9:325-333.
CREC001F

Crecelius, E.A., R.G. Riley, N.S. Bloom, and B.L. Thomas. (In press). History of contamination of sediments in Commencement Bay, Tacoma, Washington. NOAA Technical Memorandum OMPA.

Cummins, J. January, 1983-February, 1984. Personal Communication (numerous discussions with Dr. Peter Chapman). U.S. Environmental Protection Agency, Manchester, WA.

Dames and Moore. 1981. Sediments, noise, climate and air quality, aesthetics, birds. Commencement Bay Study. Vol. VII. Prepared for the U.S. Army Corps of Engineers, Seattle. U.S. Army Corps of Engineers, Seattle, WA. 157 pp.
DAME008F

Dames and Moore. 1982. Historic land use survey of the Tacoma tideflats. Report No. 82-4. Washington Department of Ecology, Olympia, WA. 76 pp.

Dames and Moore. 1983. Report of hydrogeologic site investigation. Phase II. 99 Disposal Sites near Tacoma, Washington. Prepared for the U.S. Gypsum Company, Tacoma, Washington. Dames and Moore, Seattle, WA. 52 pp.

Day, D.E. 1976. Homing behavior and population stratification in Central Puget Sound English sole (Parophrys vetulus). J. Fish. Res. Board Can. 33:278-282.

Dillon, T.M. 1984. Long-term effects of dredging operations program. Technical Report D-82-2. Biological consequences of bioaccumulation in aquatic animals: an assessment of the current literature. Final Report. National Technical Information Service, Springfield, VA.
DILL001F

Fauchald, K., and P. Jumars. 1979. The diet of worms: a study of polychaete feeding guilds. Oceanogr. Mar. Biol. Annu. Rev. 17:193-284.

Feller, L. 1981. Letter dated February 9, 1981 from L. Feller, Hooker Electrochemical Division to F. Monahon, WDOE.

Fenske, F. 1985. Internal memorandum dated April 25, 1985 from F. Fenske to J. Krull (WDOE) regarding benzo(a)pyrene measurements at Kaiser, Tacoma, WA.

Fenske, F. Personal Communication (contact by JRB Associates staff, Bellevue, WA). Washington Department of Ecology, Olympia, WA.

Folk, R.L. 1974. Petrology of sedimentary rocks. Hemphill Publishing Co., Austin, TX. 182 pp.

Fox, M.E. 1977. Persistence of dissolved organic compounds in kraft pulp and paper mill effluent plumes. J. Fish. Res. Bd. Canada 34:798-804.

Gahler, A.R., R.L. Arp, and J.M. Cummins. 1982. Chemical contaminants in edible non-salmonid fish and crabs from Commencement Bay, Washington. U.S. EPA Environmental Services Division, Seattle, WA. 117 pp.
GAHL001F

Galvin, D.V., and R.K. Moore. 1982. Toxicants in urban runoff. METRO toxicant program report No. 2. Toxicant Control Planning Section, Water Quality Division Municipality of Metropolitan Seattle, Seattle, WA.

Golucci, C. Personal Communication (contact by JRB Associates staff, Bellevue, WA). Pierce County Planning Department, Tacoma, WA.

Gossett, R.W., H.W. Pugger, and R.H. Arthur, and D.R. Young. 1983. DDT, PCB, and Benzo(a)pyrene levels in white croaker (Genyonemus lineatus) from southern California. Mar. Poll. Bull. 14:60-65.

Gray, J.S. 1982. Effects of pollutants on marine ecosystems. Neth. J. Sea Res. 16:424-443.

Guizzetti, J. Personal Communication (contact by JRB Associates staff, Bellevue, WA). Buffelen Woodworking, Tacoma, WA.

Hall, E.H. 1977. Letter dated November 4, 1977 to S. Spring, WDOE, from North Pacific Plywood Company, regarding compliance with S3 requirements under NPDES waste discharge Permit WA000203-8.

Hanneman, W.W. 1984. Analytical approaches to the characterization of selected sediments from the Hylebos Waterway and Commencement Bay, Tacoma, Washington. Attachment to Landau, 1984.

Hart-Crowser & Associates. 1976. Seepage study - stack flue Number 2, Tacoma Smelter, Ruston, Washington. Report No. J-261. Report prepared for ASARCO. Hart-Crowser & Associates, Inc., Seattle, WA.

Hart-Crowser & Associates. 1980a. Geology and hydrologic data for the Phase II groundwater study for the Hooker Chemical Plant, Tacoma, Washington. Hart-Crowser & Associates, Inc., Seattle, WA. 100 pp.

Hart-Crowser & Associates. 1980b. Phase III definition of chlorinated organic concentration within the unsaturated zone for the Hooker Chemical and Plastics Company Plant. Hart Crowser & Associates, Inc., Seattle, WA. 10 pp.

Hart-Crowser & Associates. 1983a. Phase I report: preliminary evaluation of groundwater contamination at Allied Chemical's Tacoma Works. Prepared for Allied Chemical by Hart-Crowser & Associates, Inc., Seattle, WA. 10 pp.

Hart-Crowser & Associates. 1983b. Phase II report: groundwater evaluation. Prepared for Allied Chemical by Hart-Crowser & Associates, Inc., Seattle, WA. 7 pp.

Hart-Crowser & Associates. 1984. Soil and groundwater quality evaluation, SR-705 Tacoma Spur, Tacoma, Washington. Report prepared for ABAM Engineers, WDOT and WDOE, No. J-1210-09. Unpaged.

Hart-Crowser & Associates. Undated. Geology of the Port of Tacoma. Prepared for Port of Tacoma. Hart-Crowser & Associates, Inc., Seattle, WA. 40 pp.

Hawley, G.G. (ed). 1981. The condensed chemical dictionary. Tenth Edition. Van Nostrand Reinhold Company, New York, NY. 1135 pp.

Hedges, J. Personal Communication (contact by JRB Associates staff, Bellevue, WA). Tacoma-Pierce County Health Department, Tacoma, WA.

Hedges, J.I., and J.H. Stern. 1984. Carbon and nitrogen determinations of carbonate-containing solids. Limnol. Oceanogr. 29(3):657-663.

Heffner, M. 1981. Internal memorandum dated December 7, 1981 from M. Heffner to R. Pierce (WDOE) regarding ASARCO Class II Survey - February 24 and 25, 1981.

Hendricks, J.D., T.R. Meyers, and D.W. Shelton. 1984. Histological progression of hepatic neoplasia in rainbow trout (Salmo gairdneri). Natl. Cancer Inst. Monograph 65:321-336.

High, O. Personal Communication (contact by JRB Associates staff, Bellevue, WA). Pennwalt Corporation, Tacoma, WA.

Hileman, J., and M. Matta. 1983. Commencement Bay deep water sediment investigation. Tacoma, Washington, September 15-17, 1982. U.S. EPA Environmental Services Division, Seattle, WA. 75 pp.

Holland, G.A. 1969. Age, growth and mortality of races of English sole (Paraphyrus vetulus) in Puget Sound, Washington. Pacific Marine Fish. Commission 7:36-50. 15 pp.
HOLL001F

Johnson, A., and D. Norton. 1984a. Metals concentrations in water, sediment, and fish tissue samples from Hylebos Creek drainage, August 1983 - September 1984. Completion report on WQIS Project 2 for the Commencement Bay Nearshore/Tideflats Remedial Investigation, WDOE Memorandum, January 3, 1985.

Johnson, A., and D. Norton. 1984b. Aromatic hydrocarbons and other organic compounds in groundwater beneath D Street petroleum storage facilities and in nearby City Waterway sediments, April 1984. Completion Report on WDOE Project 5 (Part 3) for the Commencement Bay Nearshore/Tideflats Remedial Investigation, WDOE Memorandum, December 21, 1984. Unpaged.

Johnson, A., and D. Norton. 1984c. Priority pollutants and other contaminants in City Waterway storm drains, September through November 1983. Completion Report on WQIS Project 5 (Part 1) for the Commencement Bay Nearshore/Tideflats Remedial Investigation. WDOE Memorandum, December 13, 1984. Unpaged.

Johnson, A., and S. Prescott. 1982a. Internal memorandum dated March 15, 1982 from A. Johnson and S. Prescott to F. Monahan (WDOE) regarding the receiving environment survey, Pennwalt Corporation.

Johnson, A., and S. Prescott. 1982b. Memorandum dated December 8, 1982 from A. Johnson and S. Prescott (WDOE) to F. Monahan (WDOE) regarding the receiving environment surveys in the Puyallup River and the Tacoma Central Sewage Treatment Plant.

Johnson, A., and S. Prescott. 1982c. Memorandum dated June 21, 1982 from A. Johnson and S. Prescott (WDOE) to D. Cunningham (WDOE) regarding the receiving environment survey at the St. Regis Paper Company.

Johnson, A., W. Yake, and D. Norton. 1983. Summary of priority pollutant data for point sources and sediment in inner Commencement Bay: Part 1. Hylebos Waterway. Washington Department of Ecology, Olympia, WA. 29 pp. JOHN001F

Johnson, E.A., L.L. Oden, and P.E. Sanker. 1982. Results of EPA extraction procedure toxicity test applied to copper reverberatory slags. U.S. Dept. of the Interior, Bureau of Mines, Report of Investigations 8684.

Johnston, S. 1981. Land and water use. Commencement Bay Study. Vol. II. Prepared for U.S. Army Corps of Engineers, Seattle. U.S. Army Corps of Engineers, Seattle, WA. 151 pp.

Jones, K.R. 1951. A survey of industrial wastes in drainage areas 11 and 12. A Publication of the Washington State Pollution Control Commission, Olympia, WA.

Kaiser Aluminum and Chemical Corporation. (No date). Report on Tacoma line V site findings. Kaiser Research Laboratory, CFT. 2 pp.

Kaiser Aluminum and Chemical Corporation. 1983. Sludge investigation results. Kaiser Aluminum and Chemical Corporation, Tacoma, WA.

Karickhoff, S.W., and K.R. Morris. 1985. Impact of tubifucid oligochetes on pollutant transport in bottom sediment. Environ. Sci. Technol. 19:51-56.

Karickhoff, S.W., D.S. Brown, and T.A. Scott. 1979. Sorption of hydrophobic pollutants on natural sediments. Water Res. 13:241-248. KARI001F

Kennedy Engineers. 1969. Comprehensive sewage plan for Pierce County, Washington. Prepared under the direction of the Pierce County Board of Commissioners. Kennedy Engineers, Tacoma, WA.

Kennedy/Jenks Engineers. 1983. Soil and groundwater contamination assessment of Commencement Bay Tar Pits. Report prepared for Burlington Northern Railroad, Seattle, Washington; Hygrade Food Products Corporation; and Joseph Simon and Sons, Tacoma, WA. 25 pp. + appendices.

Ketchen, K.S. 1956. Factors influencing the survival of the lemon sole (Parophrys vetulus) in Hecate Strait, British Columbia. J. Fish. Res. Board Can. 13:647-694.

Kleinbaum, D.G., and L.L. Kupper. 1978. Applied regression analysis and other multivariable methods. Duxbury Press, North Scituate, MA. 556 pp.

Konasewich, D.E., P.M. Chapman, E. Gerencher, G. Vigers, and N. Treloar. 1982. Effects, pathways, processes, and transformation of Puget Sound contaminants of concern. NOAA Technical Memorandum OMPA-20. Boulder, CO. 357 pp.

Kucinski, G. 9 August 1985. Personal Communication (phone by Ms. Glynda J. Steiner). Port of Tacoma, Tacoma, WA.

LaFleur, L. Personal Communication (contact by JRB Associates staff, Bellevue, WA). National Council on Air and Stream Improvement, Corvallis, OR.

Landau Associates. 1984. Report of sampling and testing Hylebos Waterway, Tacoma, Washington for Kaiser Aluminum and Chemical Corporation. Landau Associates, Edmonds, WA. 48 pp.

Lee, M.L., G.P. Prado, J.B. Howard, and R.A. Hites. 1977. Source identification of urban airborne polycyclic aromatic hydrocarbons by GC/MS and HRMS. Biomed. Mass. Spec. 4, 182-186.

Lerman, A. 1979. Geochemical processes. Water and sediment environments. John Wiley and Sons, New York, NY. 481 pp.

Malins, D.C., B.B. McCain, D.W. Brown, A.K. Sparks, and H.O. Hodgins. 1980. Chemical contaminants and biological abnormalities in central and southern Puget Sound. NOAA Technical Memorandum OMPA-2. National Oceanic and Atmospheric Administration, Boulder, CO. 295 pp.
MALI002F

Malins, D.C., B.B. McCain, D.W. Brown, A.K. Sparks, H.O. Hodgins, and S.-L. Chan. 1982. Chemical contaminants and abnormalities in fish and invertebrates from Puget Sound. NOAA Technical Memorandum OMPA-19. National Oceanic and Atmospheric Administration, Boulder, CO. 168 pp.
MALI003F

Malins, D.C., B.B. McCain, D.W. Brown, S.-L. Chan, M.S. Myers, J.T. Landahl, P.G. Prohaska, A.J. Friedman, L.D. Rhodes, D.G. Burrows, W.D. Orolund, and H.O. Hodgins. 1984. Chemical pollutants in sediments and diseases of bottom-dwelling fish in Puget Sound, Washington. Environ. Sci. Technol. 18:705-713.
MALI009F

Malins, D.C., S.-L. Chan, B.B. McCain, D.W. Brown, A.K. Sparks, and H.O. Hodgins. 1981. Puget Sound pollution and its effects on marine biota. Progress report to OMPA for the period May 1 to Sept. 30, 1980. National Marine Fisheries Service, Seattle, WA. 74 pp.
MALI007F

Martin, M., K.E. Osborn, P. Billig, and N. Glickstein. 1981. Toxicities of ten metals to Crassostrea gigas and Mytilus edulis embryos and Cancer magister larvae. Mar. Pollut. Bull. 12:305-308.

McCain, B.B., M.S. Myers, and U. Varanasi. 1982. Pathology of two species of flatfish from urban estuaries in Puget Sound. NOAA Northwest and Alaska Fisheries Center, Seattle, WA. 100 pp.
MCCA001F

Miller, B.S., B.B. McCain, and R.C. Wingert. 1977. Ecological and disease studies of demersal fishes near METRO operated sewage treatment plants on Puget Sound and the Duwamish River. Final Report. Puget Sound Interim Studies. Municipality of Metropolitan Seattle, Seattle, WA. 164 pp.
MET0013F

Monahan, F. 1978. Enforcement action against North Pacific Plywood Company, Inc., January 2, 1978. Memo to Lloyd Taylor, WDOE, February 9, 1978.

Monahan, F. Personal Communication (contact by JRB Associates staff, Bellevue, WA). Washington Department of Ecology, Olympia, WA.

Moore, S.P. 1982. Letter dated January 15, 1982, from S.P. Moore, American Test, Inc., to D. Beardsley. Hooker Chemical and Plastics Corporation.

Morgan, M., and R. Morgan. 1984. South on the sound. An illustrated history of Tacoma and Pierce County. Windsor Publications, Inc., Woodland, CA. 199 pp.

Mork, S. Personal Communication (contact by JRB Associates staff, Bellevue, WA). Tacoma Fire Department, Tacoma, WA.

Mowrer, J., J. Calambokidis, N. Musgrove, B. Drager, M.W. Beug, and S.G. Herman. 1977. Polychlorinated biphenyls in cottids, mussels, and sediment in southern Puget Sound, Washington. Bull. Environ. Contam. Toxicol. 18:588-594.
MOWR001F

Myers, M.S. 9 January 1985. Personal Communication (phone by Dr. Scott Becker). Environmental Conservation Division, Northwest and Alaska Fisheries Center, NOAA, Seattle, WA.

Nelson, D. Personal Communication (contact by JRB Associates staff, Bellevue, WA). Frontier Leather Company, Portland, OR.

Nestmann, E.R., E.G.H. Lea, T.I. Matula, G.R. Douglas, and J.C. Mueller. 1980. Mutagenicity of constituents identified in pulp and paper mill effluents using salmonella/mammalian-microsome assay. Mutation Research 79:203-212.

Nichols, J.A. 1972. Benthic community structure near the Woods Hole sewage outfall. Int. Revue ges. Hydrobiol. 62:235-244.
NICH101F

Nolan, J. Personal Communication (contact by JRB Associates staff, Bellevue, WA). Puget Sound Air Pollution Agency, Seattle, WA.

Nord, T.L. 1983. Internal memorandum dated November 1, 1983, from T.L. Nord to F.C. Fenske (WDOE) regarding Chapter 173-303 WAC Compliance Inspection at Kaiser Aluminum & Chemical Corp.

Norton, D., and A. Johnson. 1984. Metals in City Waterway sediment off American Plating Co., Inc., J.M. Martinac Shipbuilding Corp., and Fick Foundry Co., April, 1984. Completion Report on WQIS Project 5 (Part 2) for the Commencement Bay Nearshore/Tideflats Remedial Investigation, WDOE Memorandum, November 26, 1984. Unpaged.

Norton, D., and A. Johnson. 1985a. Assessment of log sort yards as metals sources to Commencement Bay Waterways, November, 1983 - June, 1984. Completion report on WQIS Project 1 for the Commencement Bay Nearshore/Tideflats Remedial Investigation. WDOE Memorandum, February 27, 1985.

Norton, D., and A. Johnson. 1985b. Memorandum dated April 9, 1985, from D. Norton and A. Johnson (WDOE) to J. Krull (WDOE) regarding completion report on WQIS Project 4: sources of sediment contamination in Sitcum Waterway, with emphasis on ores unloaded at Terminal 7. 25 pp.

Norusis, M.J. 1984. SPSS/PC: SPSS for the IBM PC/XT. SPSS Inc., Chicago, IL.

Oakden, J.M., J.S. Oliver, and A.R. Flegal. 1984. Behavioral responses of a phoxocephalid amphipod to organic enrichment and trace metals in sediments. Mar. Ecol. Prog. Ser. 14:253-257.

Oberlander, J. 1982. Letter dated June 11, 1982, from J. Oberlander, WDOE, to G. Tegen, Lilyblad Petroleum.

Oberlander, J. 1983. Letter dated July 6, 1983, from J. Oberlander, WDOE, to G. Tegen, Lilyblad Petroleum.

Orlob, G.T., D.R. Peterson, and K.R. Jones. 1950. An investigation of pollution in Commencement Bay and the Puyallup River system. Technical Report No. 8, Washington State Pollution Control Commission, Olympia, WA. 26 pp. plus appendices.
ORL0001F

O'Dell, C. Personal Communication (contact by JRB Associates staff, Bellevue, WA). Tacoma Sewer Utility, Tacoma, WA.

Osborne, J. 1980. Commencement Bay Waterways survey. September 23-24, 1980. U.S. Environmental Protection Agency Region 10, Seattle, WA. 17 pp.

Ott, F.S. 1985. Amphipod sediment bioassays: use of laboratory manipulations of grain size and toxicants to interpret field data. Ph.D. Thesis. University of Washington Fisheries Research Institute, Seattle, WA. 250 pp.
OTT 002D

Payne, J. Personal Communication (contact by JRB Associates staff, Bellevue, WA). Trace Environmental Chemistry Laboratory, JRB/SAIC.

Pearson, T.H., and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanogr. Mar. Biol. Annu. Rev. 16:229-311.
PEAR001F

Pierce, D., D. Noviello, and S. Rogers. 1981. Commencement Bay seafood consumption study - preliminary report. Tacoma-Pierce County Health Department. Tacoma, WA.

Pierce, R. Personal Communication (contact by JRB Associates staff, Bellevue, WA). Washington Department of Ecology, Olympia, WA.

Pierce, R. 15 July 1985. Personal Communication (memorandum concerning Tasks 4 and 5 review comments, Commencement Bay Nearshore/Tideflats Remedial Investigation to James Krull, Washington Department of Ecology, Olympia, WA.) Washington Department of Ecology, Southwest Regional Office, Olympia, WA.

Pierce, R., and D. Anderson. 1982a. Notes to files dated April 27, 1982, regarding ASARCO Acid Bypass - April 23, 1982.

Pierce, R., and D. Anderson. 1982b. ASARCO Inspection Report, 5/11/82.

Pierson, K.B., B.D. Ross, and C.L. Melby. 1983. Biological testing of solid phase and suspended phase dredge material from Commencement Bay, Tacoma, WA. U.S. Army Corps of Engineers, Seattle, WA. 59 pp.
PIER001D

Pitt, R., R. Sutherland, D. Renstrom, D. Galvin, and P. Bissonnette. 1981. Bellevue urban runoff project and Bellevue street sweeping demonstration project. U.S. EPA, Washington Operations Office, Bellevue, WA and U.S. EPA Municipal Environmental Research Lab, Edison, NJ. 188 pp.

Plumb, R.H., Jr. 1981. Procedures for handling and chemical analysis of sediment and water samples. Technical Report EPA/CE-81-1. Environmental Protection Agency/Corps of Engineers Technical Committee on Criteria for Dredged and Fill Material, U.S. Army Waterways Experiment Station, Vicksburg, MS. 471 pp.

Prahl, F.G., and R. Carpenter. 1979. Role of zooplankton fecal pellets in the sedimentation of polycyclic aromatic hydrocarbons in Dabob Bay, Washington. Geochim. Cosmochim. Acta 43:1959-1972.
PRAH001F

Prahl, F.G., and R. Carpenter. 1983. Polycyclic aromatic hydrocarbon (PAH)-phase associations in Washington coastal sediment. Geochim. Cosmochim. Acta 47:1013-1023.
PRAH003F

Randt, C.H. 1976. Letter dated October 19, 1976, from C.H. Randt (ASARCO) to S. Springer (WDOE).

Raven Systems & Research, Inc. 1984. Commencement Bay, Washington Nearshore/Tideflats Project, subbottom profiling task. Prepared for E.V.S. Consultants. Raven Systems & Research, Inc., Seattle, WA.

Reish, D.J., and J.L. Barnard. 1979. Amphipods (Arthropoda: Crustacea: Amphipoda). pp. 345-370. In: Pollution Ecology of Estuarine Invertebrates, C.W. Hart, Jr. and L.H. Fuller, (eds).
REIS002F

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Board Can. Bull. 191. 382 pp.

Riley, R.G., E.A. Crecelius, and D.C. Mann. 1980. Quantitation of pollutants in suspended matter and water from Puget Sound. NOAA Technical Memorandum ERL MESA 49. National Oceanic and Atmospheric Administration, Boulder, CO. 99 pp.
RILE001F

Riley, R.G. 1981. Letter dated March 3, 1981, from R.G. Riley, Battelle Pacific Northwest Laboratories, to E. Long, NOAA.

Riley, R.G., E.A. Crecelius, and M.L. O'Malley. 1981. Organic pollutants in waterways adjacent to Commencement Bay (Puget Sound). NOAA Technical Memorandum OMPA-12. National Oceanic and Atmospheric Administration, Boulder, CO. 90 pp.
RILE002F

Robbins, J.A., and D.N. Edgington. 1975. Determination of recent sedimentation rates in Lake Michigan using Pb-210 and Cs-137. Geochim. Cosmochim. Acta. 39:285-304.

Roberts, J.D., R. Stewart, and M.C. Caserio. 1971. Organic Chemistry: Methane to Macromolecules. W.A. Benjamin, Inc., Menlo Park, CA. 850 pp.

Rogers et al. 1982. Environmental monitoring of Frasier River at Prince George, chemical analyses of fish, sediment, municipal sewage, and bleached Kraft wastewater samples. Canadian Technical Report of Fisheries and Aquatic Science.

Rogers, T., E. Howard, and R. Young. 1983. Commencement Bay nearshore/tideflats drainage system investigation. Washington Department of Ecology, Olympia, WA.
TPHD001F

Royce, W.F. 1972. Introduction to the fishery sciences. Academic Press, New York, NY. 351 pp.

Ruckelshaus, M. Unpublished. Notes concerning historical industries in the tideflats area compiled on the basis of a review of information in the Tacoma Public Library. Prepared for Tetra Tech in 1985 by M. Ruckelshaus (WDOE).

Ruckelshaus, M. Unpublished notes. Washington Department of Ecology, Olympia, WA.

Ruckelshaus, M. 2 August 1985. Personal Communication (phone by Ms. Glynda J. Steiner). Washington Department of Ecology, Olympia, WA.

Sax, N.I. 1984. Dangerous Properties of Industrial Materials, 6th edition. Van Nostrand Reinhold Company, New York, NY. 3124 pp.

Schellenberg, K., C. Leuenberger, and R.P. Schwartzenbach. 1984. Sorption of chlorinated phenols by natural sediments and aquifer materials. Envir. Sci. & Tech. 18:652-657.

Shannon, C., and W. Weaver. 1949. The mathematical theory of communication. Univ. Illinois Press, Urbana, IL.

Shepard, F.P. 1954. Nomenclature based on sand-silt-clay ratios. J. Sediment. Petrol. 24:151-158.
SHEP001F

Sims, L. 1979. Internal memorandum dated October 17, 1979, from L. Sims to B. Eusebio (EPA) regarding EPA Site Inspection Report - ASARCO; Tacoma, WA.

Snedecor, G.W., and W.G. Cochran. 1980. Statistical methods. 7th edition. Iowa University Press, Ames, IA. p. 507.

Sokal, R.R., F.J. Rohlf. 1969. Biometry. W.H. Freeman & Co., San Francisco, CA. 776 pp.

Springer, S. 1975. Internal memorandum dated December 9, 1975, from S. Springer to J. Krull and R. Pine (WDOE) regarding ASARCO Class II inspection, November 18, 1975.

Springer, S. 1976. Internal memorandum dated May 21, 1976, from S. Springer to J. Krull (WDOE) regarding ASARCO.

Squire, R.A., and M.H. Levitt. 1975. Report of a workshop on classification of specific hepatocellular lesions in rats. Cancer Res. 35:3214-3223.

Stanley, R. 1983. Internal memorandum dated June 27, 1983, from R. Stanley to D. Burkhalter and J. Krull, WDOE.

Stargell, W. Personal Communication (contact by JRB Associates staff, Bellevue, WA). Champion International, Tacoma, WA.

Stein, J.E., T. Hom, and U. Varanasi. 1984. Simultaneous exposure of English sole (Parophrys vetulus) to sediment-associated xenobiotics: Part 1 - Uptake and disposition of ^{14}C-polychlorinated biphenyls and ^{3}H-benzo[a] pyrene. Mar. Environ. Res. 13:97-119.

Stewart, H.L., G. Williams, and C.H. Keysser. 1980. Histologic typing of liver tumors of the rat. J. Natl. Cancer Inst. 64:177-206.

Swartz, R. January 9 - February 3, 1984. Personal Communication (numerous discussions with Dr. Peter Chapman, E.V.S. Consultants, Vancouver, BC). U.S. Environmental Protection Agency, Newport, OR.

Swartz, R.C., W.A. DeBen, and F.A. Cole. 1979. A bioassay for the toxicity of sediment to marine macrobenthos. J. Water Pollut. Control Fed. 51:944-950.
SWAR004F

Swartz, R.C., W.A. DeBen, and K.A. Sercu. 1982a. Sediment toxicity and the distribution of amphipods in Commencement Bay, Washington, USA. Mar. Pollut. Bull. 13:359-364.
SWAR002F

Swartz, R.C., W.A. DeBen, and K.A. Sercu. 1982b. Sediment toxicity in Commencement Bay, Washington, Interim Report. U.S. Environmental Protection Agency, Envir. Research Lab., Corvallis, OR. 26 pp.

Swartz, R.C., W.A. DeBen, J.K.P. Jones, J.O. Lamberson, and F.A. Cole. 1985. Phoxocephalid amphipod bioassay for marine sediment toxicity. pp. 284-307. In: Aquatic Toxicology and Hazard Assessment: Seventh Symposium. R.D. Cardwell, R. Purdy, and R.C. Bahner (eds). ASTM STP 854. American Society of Testing and Materials, Philadelphia, PA.
SWAR009F

Tetra Tech. 1983a. Data evaluation and preliminary study design for the Commencement Bay Nearshore/Tideflats Superfund project. Prepared for the State of Washington Department of Ecology by Tetra Tech, Bellevue, WA.

Tetra Tech. 1983b. Site safety plan guidelines for Commencement Bay Nearshore/Tideflats Remedial Investigation. Tetra Tech, Inc., Bellevue, WA.

Tetra Tech 1984a. A decision-making approach for the Commencement Bay Nearshore/Tideflats Superfund Project. Prepared for the Washington State Department of Ecology. Tetra Tech, Inc., Bellevue, WA. 64 pp.
TTB 010F

Tetra Tech. 1984b. Sampling and analysis plan. Report prepared and modified by Brown and Caldwell and E.V.S. Consultants for the Commencement Bay Superfund Project, Washington Department of Ecology, Olympia, WA. 43 pp.

Tetra Tech. 1985. Potential remedial technologies for the Commencement Bay Nearshore/Tideflats Remedial Investigation. Prepared for the Washington State Department of Ecology and the U.S. EPA. Tetra Tech, Inc., Bellevue, WA.

Thompson, S., and G. Eglinton. 1978. The fractionation of a recent sediment for organic geochemical analysis. Geochim. Cosmochim. Acta 42:199-207.

U.S. Environmental Protection Agency. 1975. Survey of Industrial Processing Data. Task 1 - Hexachlorobenzene and Hexachlorobutadiene Pollution from Chlorocarbon Processing. EPA 560/3-75/003.

U.S. Environmental Protection Agency. 1980a. Ambient Water Quality Criteria: Hexachlorobutadiene. EPA 440/5-80-053, U.S. Environmental Protection Agency, Washington, DC.

U.S. Environmental Protection Agency. 1980b. Ambient Water Quality Criteria: Pentachlorophenol. EPA 400/5-80-065, U.S. Environmental Protection Agency, Washington, DC.

U.S. Environmental Protection Agency. 1980c. Ambient Water Quality Criteria: Dichlorobenzene. EPA 440/5-80-039, U.S. Environmental Protection Agency, Washington, DC.

U.S. Environmental Protection Agency. 1982. Unpublished sediment data. Letter from D.W. Schultz, U.S. EPA Marine Science Center, Newport, OR, to Art Johnson, Washington Department of Ecology, Olympia, WA.

U.S. Environmental Protection Agency. 1983a. Health assessment summary of 300 hazardous organic constituents. Unpublished file memorandum from Michael Dourson. U.S. EPA Environmental Criteria and Assessment Office, Cincinnati, OH.

U.S. Environmental Protection Agency. 1983b. Inorganic arsenic emissions from high arsenic primary copper smelters: background information for proposed standards. EPA 450/3-83-009A. U.S. EPA, Air Quality Planning and Standards, Research Triangle Park, NC.

U.S. Environmental Protection Agency. 1983c. List of hazardous substances and reportable quantities. U.S. EPA, Washington, DC. Federal Register, Vol. 48, No. 102. p. 23579.

U.S. Environmental Protection Agency. 1984. Health assessment document for tetrachloroethylene. External review draft report. U.S. EPA Office of Health and Environmental Assessment, Washington, DC.

Van Es, F.B., M.A. Van Arkel, L.A. Bouwman, and H.G.I. Schroeder. 1980. Influence of organic pollution on bacterial, macrobenthic, and meiobenthic populations in the intertidal flats of the Dollard. Neth. J. Sea Res. 14:288-304.
VANE001F

Varanasi, U., and D.C. Malins. 1977. Metabolism of petroleum hydrocarbons: accumulation and biotransformation in marine organisms. pp. 175-270. In: Effects of Petroleum on Arctic and Subarctic Marine Environments and Organisms. Vol. II. Biological Effects. D.C. Malins (ed). Academic Press, San Francisco, CA.

Versar, Inc. 1985. Assessment of human health risk from ingesting fish and crab from Commencement Bay. EPA 910/9-85-129. Prepared by Versar, Inc., Springfield, VA.

Wallin, B., and A.J. Condren. 1981. Project summary: fate of toxic and nonconventional pollutants in wastewater treatment systems within the pulp, paper, and paperboard industry. EPA-600/52-81-158.

Walker Wells, Inc. 1980a. Groundwater quality and corrective-action concerns at the Hooker Plant, Tacoma, Washington. Walker Wells, Inc., Champaign, IL. 40 pp.

Walker Wells, Inc. 1980b. Groundwater conditions in the vicinity of the Tacoma, Washington (Hooker Chemical) plant. Phase II. Walker Wells, Inc., Champaign, IL. 47 pp.

Walker Wells, Inc. 1981. Monitoring well network for the old solvents plant area at the Tacoma, Washington plant. Walker Wells, Inc., Urbana, IL.

Wigington, P.J., C.W. Randall, and T.J. Grizzard. 1983. Accumulation of selected trace metals in soils of urban runoff detection basins. Water Resources Bulletin 19(5):709-718.

Winer, R.J. 1971. Statistical principles in experimental design. Second Edition. McGraw-Hill Book Company, New York, NY. 907 pp.
WINE001F

Wolfe, D.A., D.F. Boesch, A. Calabrese, J.J. Lee, C.D. Litchfield, R.J. Livingston, A.D. Michael, J.M. O'Connor, M. Pilson, and L.V. Sick. 1982. Effect of toxic substances on cummunities and ecosystems. pp. 67-86. In: Ecological Stress and the New York Bight: Science and Management. G.F. Mayer (ed). Estuarine Research Federation, Columbia, SC.
WOLF001F

Wong, P. 1982. Internal memorandum dated July 1, 1982, from P. Wong to John Barich, Chief, Superfund Branch, EPA.

Word, J.Q. 1978. The infaunal trophic index. pp. 19-39. In: Coastal Water Research Project Annual Report. SCCWRP, El Segundo, CA.
WORD008F

Word, J.Q. 1980. Classification of benthic invertebrates into infaunal trophic index feeding groups. pp.103-121. In: Coastal Water Research Project, Biennial Report for the Years 1979-1980, W. Bascom (ed). SCCWRP, Long Beach, CA.
WORD007F

Yake, B. 1980. Internal memorandum dated June 4, 1980, from B. Yake to F. Monahan, WDOE, regarding Hooker Chemical Corporation Class II inspection.

Yake, B. 1982a. Internal memorandum dated March 9, 1982, from B. Yake to F. Monahan, WDOE, regarding Pennwalt Corporation Class II inspection.

Yake, B. 1982b. Memorandum dated June 1, 1982, from B. Yake (WDOE) to F. Fenske (WDOE) regarding St. Regis Paper Company Class II Survey.

Yake, B. 1982c. Memorandum dated October 5, 1982, from B. Yake (WDOE) to F. Monahan (WDOE) regarding the Tacoma Central Sewage Treatment Plant Class II Survey.

Young, D.R., G.V. Alexander, and D. McDermott-Ehrlich. 1979. Vessel-related contamination of southern California harbors of copper and other metals. Mar. Pollution Bull. 10:50-56.

Youngblood, W.W., and M. Blumer. 1975. Polycyclic aromatic hydrocarbons in the environment: homologous series in soils and recent marine sediments. Geochim. Cosmochim. Acta 39, 1303-1314.

Zar, J.H. 1974. Biostatistical analysis. Prentice-Hall, Inc. 620 pp.
ZAR 001F